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PROCEEDINGS

OF THE

AMERICAN ACADEMY

OF

ARTS AND SCIENCES.

VOL. XIX.

PAPERS READ BEFORE THE ACADEMY.

I.

CONTRIBUTIONS TO NORTH AMERICAN BOTANY.

BY ASA GRAY.

Presented May 9, 1883. — Issued Oct. 30, 1883.

I. *Characters of New Compositæ, with Revisions of certain Genera, and Critical Notes.*

Eupatoriaceæ.

STEVIA AMABILIS, Lemmon. *S. laxifloræ* peraffinis, gracilior, bipedalis; foliis omnibus linearibus basi attenuatis (sesquipollicaribus) integerrimis; capitulis effuso-paniculatis; floribus læte purpureis; pappi paleis 5 cum aristis alternantibus brevissimis. — S. Arizona in the plains near Cave Cañon, *Lemmon.* The narrowest-leaved forms referred to *S. laxiflora* (coll. *Wislizenus, Schaffner*) notably approach this.

Asteroideæ.

APLOPAPPUS (ERICAMERIA) MONACTIS. Facie *A. laricifolii*, frutex fastigiato-ramosissimus, 1–5-pedalis, vix resinosus; foliis aceroso-linearibus fere impunctatis; capitulis corymboso-cymosis paucifloris; involucro oblongo 8–10-phyllo; bracteis chartaceis oblongis vel sublanceolatis obtusis; floribus hermaphroditis 5 vel 6, corollæ lobis ovato-oblongis, styli ramis latiusculis appendice subovata acuta superatis; fœmineo unico (interdum nullo), ligula elongato-oblonga; acheniis sericeo-villosis; pappo albo molli. — Borders of the Mohave

Desert, S. E. California, *Palmer* (1876, confounded with *A. laricifolius*), *S. B. & W. F. Parish* (1881), *Pringle*, 1882.

GREENELLA DISCOIDEA. Ramis strictis fastigiatis; capitulis minoribus; ligulis nullis; ovariis glabris demum secus costas minutissime puberulis; pappi corona pluricrenulato nudo. — S. Arizona, in Tanner's Cañon, Sept., *Lemmon.* — *G. Arizonica*, which has been freely distributed by Lemmon and Pringle, by the latter in fruit, has the mature akene very villous, in the manner of *Gutierrezia eriocarpa*, &c. If, disregarding the color of the ray-flowers, this genus were referred to *Gutierrezia*, both would have to be combined with *Xanthocephalum*, which would hardly do.

ERIGERON ARIZONICUS. Ultrapedalis e radice ut videtur annua, ramosus, pube patente cinerea undique hirsutus; foliis fere integerrimis (1–2-pollicaribus), radicalibus oblongo-obovatis in petiolum angustatis, caulinis plerisque lanceolatis acutis arcte sessilibus; ramis monocephalis; involucro (lin. 3–4 alto) cinereo-hirsuto; ligulis (lin. 4 longis) perplurimis angusto-linearibus albis; acheniis obovato-oblongis hirsutulis binervatis; pappo duplici, exteriori setoso-squamellato conspicuo. — S. Arizona, near Tanner's Cañon, Huachuca, *Lemmon.*

ERIGERON NEO-MEXICANUS. *E. delphinifolio* similis; differt (ut dixit Benth.) pube hispida patente, lobis foliorum superne latioribus, ligulis minus numerosis parum latioribus. — *E. delphinifolius*, Gray, Pl. Wright. ii. 77, & Bot. Mex. Bound. 78, non Willd. & HBK. — New Mexico and Arizona, *Wright*; *Bigelow*, *Thurber*, *Palmer*, *Lemmon.* Bentham (in Gen. Pl. ii. 281) indicated this as distinct from the Mexican species; and the differences, though not great, seem to be constant.

ERIGERON LEMMONI. Inter Boreali-Americanas anomalus, e radice perenni diffuso-decumbens, ramosissimus, pube hirsutula cinereus; ramis gracilibus foliosissimis; foliis (parum semipollicaribus) spathulatis, caulinis sæpius 3–5-lobatis seu laciniato-dentatis, ramealibus integerrimis; capitulis brevi-pedunculatis parvis (lin. 2 altis); involucro hirsutulo, bracteis subulatis subæqualibus; ligulis 40–50 purpureis discum longius superantibus; pappo e setis pauciusculis cum setulis minimis. — S. Arizona, in Tanner's Cañon of the Huachuca Mountains, with "stems sometimes 2 feet long," in the specimens a span or two long, *Lemmon.*

ERIGERON OREGANUS. Ut videtur biennis, pube molli tenui pubescens; caulibus e rosula foliorum radicalium plurimis ultraspithamæis debilibus foliosis apice 1–4-cephalis; foliis spathulatis imisve obovato-cuneatis, radicalibus 3–5-lobatis vel inciso-dentatis; capitulis brevi-

pedunculatis iis *E. bellidifolii* referentibus sed minoribus, ligulis minoribus angustioribus pallide purpureis; acheniis hirsutis; pappo prorsus simplici. — *E. pulchellus* var., Hook. Fl. ii. 19? — Oregon, along the Columbia River, under overhanging cliffs, in Multnomah Co., *Howell.* — This must rank near *E. Philadelphicum.*

Inuloideæ.

FILAGO DEPRESSA. Soror *F. Californicæ*, sed a basi ramosissima, humistrata, internodiis omnibus brevibus; bracteis fl. fœmineis angustioribus; acheniis obovatis lævibus. — Desert of San Bernardino Co., California, at Hot Springs, &c., *Parry*, 1876 (incomplete specimens), *Parish*, 1882.

GNAPHALIUM PANNOSUM. Lana densa undique incanum; caulibus e radice annua vel lignescente adscendentibus pedalibus simplicibus; foliis spathulatis, radicalibus amplis obovatis triplinerviis (pollicem latis), caulinis semiamplexicaulibus vix decurrentibus, superioribus oblongis (pollicaribus); capitulis glomeratis; involucri bracteis sordide albidis oblongis obtusiusculis. — Mexico, in the mountains near San Luis Potosi, *Schaffner*, 227. *Parry & Palmer*, 420. Habit unlike any of the ordinary Mexican species.

GNAPHALIUM ARIZONICUM. Griseo-lanatum; caulibus gracilibus strictis e radice annua; foliis infimis oblanceolatis brevibus; cæteris angustissime linearibus (lin. latis) basi tenuiter breviter decurrentibus; capitulis parvulis in glomerulis cymoso-fastigiatis aggregatis; involucro oblongo fusco, bracteis oblongo-lanceolatis plerisque acutis tenuibus. (Juxta *G. microcephalum* collocandum.) — S. Arizona, near Fort Huachuca, along exsiccated beds of streams, *Lemmon.*

GNAPHALIUM BOURGOVII. Foliis linearibus attenuato-acutis basi longius alato-decurrentibus supra glabratis lævibus subtus cauleque leviter araneoso-lanatis; involucri bracteis albidis obtusiusculis oblongis, intimis lanceolatis. — Mexico, valley of Cordova, *Bourgeau*, no. 1852.*

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* The Mexican species greatly need revision, and the collocation of original specimens.

G. OXYPHYLLUM, DC. To this is referred no. 551 of coll. Palmer, a woolly form, from near Saltillo, where Gregg collected a form (415) with the wool deciduous, and the somewhat viscid hairiness well developed. Of the same species are Coulter's 451, Parry & Palmer's 417, specimens from Botteri, and one received from Schultz Bip., collected by Schaffner at the foot of Chapultepec, and ticketed "*G. hirtum*, HBK." It may be so; but the leaves are not glaucescent beneath, nor the involucral bracts "argute acutis flavescentibus." The *G. inornatum*, DC., of which no authentic specimens are at hand, may be a

Helianthoideæ.

Silphium albiflorum. *S. laciniato* affinis, humilius (1–3-pedale); foliis minoribus circumscriptione sæpius rotundatis, petiolo basi dilatato integerrimo; involucro discum haud superante; ligulis albis; acheniis puberulis apice bidentato-alatis et subulato-biaristatis, dentibus aristæ pl. m. exsertæ adnatis. — On limestone rocks, in prairies or on low bluffs, Western and Northern Texas, *Reverchon*. Peculiar in the genus for its white rays, and distinct from the ordinary Compass-plant in the akenes and other particulars.

Wyethia longicaulis. *W. amplexicauli* peraffinis, elatior; foliis lanceolatis, caulinis omnibus basi angustatis nec amplexicaulibus; capitulis plerumque longe pedunculatis; involucri bracteis exterioribus majoribus foliosis; pappo brevi coroniformi multi-crenulato vel eroso. — Prairies of E. Humboldt Co., California, *V. Rattan*, incomplete specimens in 1876, good ones in 1883.

Gymnolomia encelioides. Annua, strigoso-incana; caule ramoso hispidulo; foliis longiuscule petiolatis ovato-oblongis obtusis subintegerrimis, superioribus alternis; involucro (lin. 5 alto) biseriali, bracteis exterioribus oblongo-lanceolatis acutis cano-pubescentibus nunc hispidulis æqualibus interiores sublineares minores paullo superantibus; receptaculo et disco parum convexis; ligulis 10–12 ovalibus vix pollicaribus aureis; corollis disci apice atro-purpureis; bracteis receptaculi apice trifidis; acheniis obovato-oblongis inferne parce versus apicem crebre villosis; pappo aut nullo aut squamellis setiformibus minimis inter pilos achenii summos. — Mohave Desert, near Agua Caliente, S. E. California, *S. B. & W. F. Parish*, April, 1882. This has the habit of an *Encelia;* but the nearly full-grown akenes are not flat nor acute-edged.

Gymnolomia ovata. Caule stricto herbaceo 2–3-pedali; foliis ovatis brevissime petiolatis serrulatis (sesquipollicaribus) venosis tri-

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small-leaved form of *G. oxyphyllum;* and the branches of Parry & Palmer's 417, as also a part of Coulter's 451, answer to the character. Lanate forms of the species seem to pass into *G. brachypterum*, DC., the originals of which are Berlandier's 769 and 2189. Ghiesbreght's 161, Linden's 1191, and a plant of Schaffner's collection, sent by Schultz as *G. oxyphyllum*, are the same.

G. attenuatum, DC. To this may be referred Liebmann's 309, from Colepa, and a quite similar plant from Orizaba by Schaffner; both have been named *G. Berlandieri*, DC. (of which I have no specimen), but they do not agree with the character of that species, as they do with that of *G. attenuatum;* and they differ from *G. oxyphyllum* in the particulars which DeCandolle mentions. Schultz's determination must have been a mistaken one.

nervatis pube brevi subtus molli supra strigulosa canescentibus; capitulis parvulis paucis in pedunculo communi; involucro campanulato lin. 3–4 alto, bracteis angustis lineari-lanceolatis cinereis; ligulis (lin. 3 longis) 8–10 pallide luteis; disco convexo; acheniis glaberrimis calvis. — Chiapas, Mexico, in forests on the mountain-sides, *Ghiesbreght*, 554.

GYMNOLOMIA PLATYLEPIS. *Tithonia platylepis*, Schultz Bip., and *Mirasolia scaberrima*, Benth. & Hook. This is obviously one of the latibracteate *Gymnolomiæ*. And the genus *Mirasolia* of Schultz Bip. may be suppressed; for the *Tithonia calva*, Schultz, if not truly of that genus, wanting the pappus, may likewise be referred to *Gymnolomia;* and the following is certainly a *Tithonia*.

TITHONIA DIVERSIFOLIA. *Mirasolia diversifolia*, Hemsl. Biol. Centr.-Am. Bot. ii. 168, t. 47. This striking species, collected by Botteri and Bourgeau in the vicinity of Orizaba and Cordova, we take to be a strict congener of *T. tagetiflora* and *T. speciosa*. One or both of the awns or aristiform paleæ of the pappus are not rarely developed.

VIGUIERA DECURRENS. *Tithonia decurrens*, Gray, Pl. Fendl. 85, by misprint "*recurrens*" in Hemsl. Biol. Centr.-Am. Known only from the specimen of Wislizenus, of which I possess merely a part. But it is a *Viguiera* of the same section with *V. excelsa* (which apparently includes the *Tithonia pachycephala*, DC.) and the very similar *V. urticiformis* (*Leighia*, DC., with which Schaffner's no. 267 agrees); also *V. buddleiformis*, Benth. & Hook. The latter appears to include *Helianthus rugosus*, Schauer in Linnæa. And the squamellæ being deciduous as well as the paleaceous awns, this species should rather be restored to *Helianthus*.

VIGUIERA BLEPHAROLEPIS. Frutescens? pube minuta canescens; caulibus ramisve monocephalis; foliis oppositis lanceolatis summisve linearibus acutiusculis basi attenuata sessilibus subintegerrimis supra scaberrimis subtus triplinerviis, venulis reticulatis; involucro (ultra-semipollicari) lato-campanulato pluriseriatim imbricato; bracteis conformibus erectis fere siccis oblongo-spathulatis apice rotundatis margine insigniter hispido-ciliatis, interioribus sensim majoribus; ligulis sublinearibus; acheniis villosis; pappo ut videtur persistente pluri-paleaceo et biaristato, aristis subulatis achenio subæquilongis, paleolis oblongis sæpius inæqualibus, majoribus aristis parum dimidio brevioribus. — Northwestern Mexico, *Seemann*. Apparently not referred to in the Botany of the Herald. My specimen is ticketed "*Tithonia angustifolia*, Hook. & Arn.," which species Bentham refers to *V. buddleiformis*, doubtless correctly. This, although of the same group, is very

distinct, and in some respects much resembles *V. sericea* (*Harpalium sericeum*, DC.), of Peru. The dense and rigid ciliation of the involucre is characteristic.

VIGUIERA HELIANTHOIDES, HBK. Adopting Bentham's reference of DeCandolle's *V. laxa* and *V. brevipes* to this, the original of the genus, one may confidently add *V. Sagræana* and *V. dentata*, perhaps all of DeCandolle's first section, and at least two of the second. *V. dentata*, the *Helianthus dentatus*, Cav., appears to be well matched by Parry & Palmer's no. 471½, and by corresponding specimens from Schaffner, with upper leaves mainly opposite; also, although the leaves are alternate, by Parry & Palmer's 467, and Bourgeau's 365 and 1222, which Hemsley records as two undetermined species. (No. 1222 has rays in one of our specimens.) In no specimens, even the Cuban, do I find the receptacle so high and narrow as in Kunth's figure; and at first the disk is commonly so low that DeCandolle referred some of the members of this species to his second section. When growing in moist soil and shade the leaves are thin and green (as in *V. Texana*, Torr. & Gray), in drier and more exposed situations they are thicker, smaller, rather rigid, sometimes cinereous, as in *V. brevipes*.

VIGUIERA CANESCENS, DC., although near the preceding, appears to be a distinct species, having more rigid leaves and akenes whitened by a dense and fine silky villosity. It has been collected by Palmer in Northern Mexico, and by Pringle in Arizona.

VIGUIERA GHIESBREGHTII. Undique hispidula; caulibus gracilibus oligocephalis; foliis lanceolatis subintegerrimis concoloribus leviter triplinerviis subsessilibus, inferioribus oppositis; capitulis iis *V. buddleiformis* minoribus; involucri bracteis paucioribus minus patentibus, extimis brevibus lanceolatis, intimis oblongo-spathulatis discum subsuperantibus; ligulis linearibus; acheniis (immaturis) fere glabris; pappo pluri-squamellato et 1–3-aristato deciduo. — Mexico, in pine forests near Morelia, *Ghiesbreght*, no. 381 of an old collection.

VIGUIERA SESSILIFOLIA, DC. We seem to have this in no. 453 of Parry & Palmer's collection. But the truncate paleæ are more than four, unless they are early fissile. No. 458 of the same collection seems to be a broad-leaved form of *V. excelsa*, Benth. & Hook. No. 452 is, with little doubt, a state of *V. cordifolia*, Gray.

VIGUIERA PERUVIANA, Gray, Proc. Am. Acad. v. 124, appears to be only a glabrate state of *Helianthus aureus*, HBK., the *Harpalium aureum*, DC.

VIGUIERA PŒPPIGII. *Helianthus corymbosus*, Pœpp. Pl. Exsic. *Flourensia corymbosa*, DC. Prodr. v. 592. That this is a true *Viguiera*

has been noted by Bentham and others. The published specific name of *corymbosa* is quite inapplicable to a plant with elongated and single monocephalous peduncles.

What should be done with the other radiate *Flourensia* of DeCandolle, *F. thurifera*, seems uncertain. Perhaps it should be retained as a section of that genus, under Bertero and Colla's name (not Cassini's) of *Diomedea*. It is no *Helianthus*. And the following is still farther from that genus.

Flourensia cernua, DC. l. c.; Gray, Pl. Wright., &c. Hemsley calls this "*Helianthus cernua*, Benth. & Hook. Gen. Pl. ii. 376"; but Bentham, in the work cited, can hardly be said even to refer this and its true congener (notwithstanding the different habit) *F. laurifolia*, DC., to *Helianthus*, although he has not otherwise disposed of these peculiar species. They may justly be regarded as the type of *Flourensia*, for DeCandolle figured *F. laurifolia* to illustrate his genus, which, thus restricted, is a very good one. But DeCandolle's character "corollæ disci faux vix tubo latior" is inapplicable to these species, as also to *F. thurifera*. They have a rather slender proper tube, which is abruptly enlarged into the much broader and campanulate or cylindraceous throat.

Helianthus Parishii. *H. Californico* affinis, ultra-orgyalis; foliis elongato-lanceolatis pube molli brevi cineris vel canescentibus supra scabris; capitulis semipollicem altis; ligulis ultrapollicaribus; involucri bracteis lineari-subulatis disco longioribus basi villosis; corollis disci supra tubum sericeo-annulatis; pappi paleis tenui-subulatis. — S. E. California, near San Bernardino, in wet places and along streams, *S. B. & W. F. Parish.*

Encelia. The presence or absence of pappus proves to be unimportant, and far from constant in the same species. Wherefore, in adopting Bentham's rightful consolidation, the primary sections should be reduced, by referring *Geræa* to *Euencelia*, and *Barrattia* to *Simsia*.

Encelia microphylla, Gray, Proc. Am. Acad. xv. 37, a Northern Mexican species, of which mature fruit has recently been collected by Palmer, has shrubby stems, foliage not unlike that of *Flourensia cernua*, and the relationship of the two is apparent. It has a pappus of two slender villous awns, which sometimes barely equal and sometimes much surpass the white villosity of the akene.

Encelia scaposa, *Simsia* (*Geræa*) *scaposa*, Gray, Pl. Wright. ii. 88, is of the genus; but not *E. microcephala*, which is a genuine *Helianthella*, to a peculiar section of which must be referred the anomalous *E. nudicaulis* and *E. argophylla*.

ENCELIA STENOPHYLLA, E. L. Greene, is a simpler species, with aristate akenes and filiform leaves, from Cedros Islands, Lower California.

ENCELIA HALIMIFOLIA, Cav. Ic. iii. 6, t. 210. This was raised from seeds said to come from "Nova Hispania," i. e. Mexico, and was characterized by "calycibus ciliatis," that is, the involucre with "squamulis ciliatis." Instead of this, DeCandolle, in the Prodromus, has it that the "leaves" are "margine valde ciliatis," which was probably a slip, and as to habitat adds "verosimiliter potius in Peruvia." Now we have a specimen collected by Palmer on the Yaqui River, in the Mexican province of Sonora, which accords well with the original character and figure. *E. conspersa*, Benth. Bot. Sulph., of Lower California, from the description may be the same.

The species of the section SIMSIA, chiefly Mexican, greatly need revision. Hemsley, in the Biol. Centr.-Amer. Bot., has enumerated them from the books; but they should be reduced and characterized by some botanist having access to original specimens. Only three of them occur in the United States; viz. E. EXARISTATA, Gray in Hemsl. l. c., an annual species (which is *S. lagascæformis* of Pl. Wright.), and two nearly related perennials, E. SUBARISTATA, Gray, l. c., and E. CALVA, the *Barrattia calva* of Gray & Engelm. *E. exaristata* is said by Hemsley to be no. 3320 of Bourgeau's collection from Orizaba; but I have it only from S. W. Texas and Arizona, collected by Wright, Thurber, and Lemmon. It is an annual with (so far as known) undivided leaves and appendaged petioles, rather small or narrow heads, an unequal involucre of lanceolate bracts, the inner minutely glandular, rays few and not surpassing the disk, and very smooth and glabrous akenes slightly emarginate at summit, the pappus wanting or minutely biaristellate.

ENCELIA MEXICANA, Mart., a name taken up by Hemsley from DeCandolle's mention, seems to be the best available name for the most common and polymorphous Mexican species, and the one longest known. It is *Coreopsis fœtida*, Cav., therefore *Simsia ficifolia*, Pers., and *Encelia fœtida*, Hemsley, *Simsia auriculata*, DC., and probably *S. amplexicaulis*, Pers., *E. amplexicaulis*, Hemsley. It is also, without much doubt, the *Helianthus amplexicaulis*, DC. Prodr. v. 589. A slender form of it with undivided leaves and exappendiculate petioles is *Simsia Schaffneri*, Schultz Bip., which grows with the ordinary state. A more robust form, also of Schaffner's collection, with large undivided leaves and auriculate appendaged petioles, is *Simsia cordata* of Schultz Bip., probably also of Cassini (*Ximinesia cordata*, HBK.,

Encelia cordata, Hemsley). The root is annual; the involucre between hispid and hirsute; and the akenes obovate-oblong, with shallow notch, pilose-pubescent on the faces, more ciliate towards the summit; awns of the pappus rather long, with more or less scarious-dilated base often fringed with two or three teeth or setæ on each side.

ENCELIA LAGASCÆFORMIS (*Simsia*, DC.) is taken up by Hemsley from my naming after Bentham; but the plants of Hartweg, of Ervendberg, and of Parry & Palmer, cannot be DeCandolle's. They have rather the characters of *E. Mexicana* in a depauperate state. DeCandolle's species is much better represented by a specimen in our herbarium — an imperfect one — from Botteri's collection around Orizaba; slender, with small and narrow heads, an involucre which accords with DeCandolle's character in having (broadly) lanceolate bracts, the outer only half the length of the inner (but these are villous rather than hispid), the rays "about 5" and exserted, the akenes quite glabrous. As the awns are wanting in the specimen, this may be identical with Bourgeau's 3320, referred by Hemsley to *E. exaristata*, to which it is obviously related.

ENCELIA HETEROPHYLLA, Hemsley, l. c., I know only from the figure of *Ximinesia heterophylla*, HBK. It is said to be perennial and yellow-flowered. One may suspect that *E. sanguinea*, Hemsley (*Simsia sanguinea*, Gray, Pl. Wright. i. 107, also distributed by Schultz Bip. as *S. erythranthema*) is only a red-flowered variety of it.

ENCELIA GHIESBREGHTII, Gray, Proc. Am. Acad. viii. 658, has a peculiar habit, in foliage and pubescence agreeing well with the description of *E. sericea*, Hemsley, l. c. It is probably a perennial. The fruit is not sufficiently developed to make sure of the genus.

HELIANTHELLA § ENCELIOPSIS. A subgenus formed for the reception of two anomalous scapose perennials, thick-leaved, silvery-canescent, with large solitary heads (the disk an inch broad and flat); paleæ of receptacle soft and scarious; achenia flat, oblong-cuneate, very villous, with narrow callous margins and summit, the latter bordered between the short subulate awns by a very short fringe of membranaceous and confluent squamellæ.

H. NUDICAULIS. *Encelia* (*Geræa*) *nudicaulis*, Gray, Proc. Am. Acad. viii. 656. Mr. Shockley has recently sent it from the western part of Nevada.

H. ARGOPHYLLA. *Tithonia argophylla*, Eaton in Bot. King. 423. *Encelia* (*Geræa*) *argophylla*, Gray, l. c. This is still imperfectly known.

HELIANTHELLA proper. In revising this genus I find that the following species may be associated as having soft-scarious chaff of

the receptacle, and more or less of long villosity at least on the margins of the akenes; viz. *H. quinquenervis* (the large-flowered *Helianthella uniflora*, so called, of the Colorado Rocky Mountains, extending to the British boundary, but not of Nuttall in coll. Wyeth, nor of his character in Trans. Am. Phil. Soc., though he mixed the two in his own collection: it is the *Helianthus quinquenervis*, Hook. Lond. Jour. Bot. vi. 247, of Geyer's collection); *H. Parryi; H. Mexicana; H. microcephala*, the *Encelia microcephala*, Gray, Proc. Am. Acad. viii. 657. The following have chaff of a firmer or chartaceous texture: *H. lancelata*, with hirsute or hispidulous loose pubescence and no long villosity to the ovary or akene; *H. Douglasii*, still known only by the specimen in the Hookerian herbarium, perhaps a form of the preceding; *H. uniflora*, with fine and close pubescence, and more or less villous akenes, at least on the margins (*H. multicaulis*, Eaton, is a form of this, his *H. uniflora* being our *H. quinquenervis*); and *H. Californica*, with nearly all the leaves petioled, and the ovary and akene quite glabrous.

OYEDÆA SEEMANNI. *Viguiera Seemanni*, Schultz Bip. in Bot. Herald, 305; Hemsl. Biol. Centr.-Am. Bot. ii. 178. Good fruit is still needed; but the ovary is glabrous on the sides and with acute edges, and the habit is wholly of *Oyedæa*, to which the plant probably belongs.

ZEXMENIA HISPIDA. *Z. Texana*, Gray, Pl. Wright. i. 112, Bot. Mex. Bound. 92. In the first-mentioned publication the resemblance of our Texan plant to *Wedelia hispida*, HBK., is noted; in the second, the identity is affirmed. This is now beyond question, wherefore it is best to reinstate the original specific name. Bentham and Hooker, in Gen. Pl., still leave Kunth's plant, and therefore Cassini's *Stemmodontia*, in *Wedelia*, while yet recognizing the Texan plant as a *Zexmenia*. The former reference is probably from the published figure, which wants the fruit; the latter, from numerous specimens. The name of the section should be *Stemmodontia*.

ZEXMENIA BREVIFOLIA, Gray, Pl. Wright. i. 112. Nearer than the preceding species to true *Zexmenia*. Although the akenes are, as Bentham states, "sæpe vix alata," yet they are often surmounted by a strong callous wing. Squamellæ of the pappus sometimes very conspicuous, sometimes obsolete in age.

ZEXMENIA AUREA, *Wedelia aurea*, Don in Bot. Mag. t. 3384 (*Verbesina*, DC.), referred here by Bentham (although there are no squamellæ), has been distributed from a collection of Schaffner's (no. 56) as *Z. tuberosa*. The roots swell and become tuber-like.

ZEXMENIA FASCICULATA, Schultz Bip. in Seem. Bot. Herald, 306, taken up later by Hemsley, is not wholly "discoid" as DeCandolle states, some of Berlandier's own specimens having rays. Perhaps it too nearly approaches the narrower-leaved forms of *Z. ceanothifolia*, Schultz, at least as to the *Lipochata umbellata*, DC., of Berlandier's collections.

ZEXMENIA CROCEA, Gray, Pl. Wright. i. 114. To this belongs *Z. stenantha*, Hemsley, Biol. Centr.-Am. Bot. ii. 147. The narrow disk-corollas are common to all the species of this *Lasianthæa* group. From the specific name, it is probable that the unpublished *Z. tagetiflora* of Don, enumerated in Steudel's Nomenclator, is of this species.

ZEXMENIA HELIANTHOIDES, Gray, l. c. To this must belong the *Tithonia ovata*, Hook. Bot. Mag. t. 3901, referred to the genus by Bentham, and taken up as *Z. ovata*, Benth. & Hook., by Hemsley.

VERBESINA, L., partly. It is no longer practicable to keep *Actinomeris* apart from *Verbesina* upon the character of neutral or infertile (although styliferous) rays. Yet the former genus may be kept up for the species upon which Nuttall really established it, relying mainly on the globose head, becoming squarrose in fruit, and the simple small involucre. For the rest, there is neither character nor habit to distinguish the species from *Verbesina*. The North American and Mexican species known to me fall under the following sections or subgenera.

§ 1. VERBESINARIA, DC. Capitula sat angusta, parvula, sæpius cymoso-aggregata vel paniculata: involucrum imbricatum: ligulæ haud numerosæ plerumque fertiles, rarius nullæ: aristæ pappi haud hamatæ.

* Achenia prorsus aptera: receptaculum fere planum: ligulæ 1–5 cum fl. disci luteæ: folia opposita secus caulem decurrentia.

V. OCCIDENTALIS, Walt. Car. 213, a name to be restored for *V. Siegesbeckia*, Michx. Besides being the oldest name under the genus, this is *Siegesbeckia occidentalis*, L. Atlantic U. S.

* * Achenia omnia vel nonnulla alata: receptaculum convexum vel conicum.

V. VIRGINICA, L., is the only N. American species (of the Atlantic States); it has small white-flowered and 3–5-ligulate heads. It includes *V. microptera* and *V. polycephala*, DC., and as a var. (LACINIATA) *V. laciniata*, Nutt., which is *V. sinuata*, Ell. Also, as an anomalous form, —

Var. PALMERI Vegetior, viridior; foliis majoribus (semi- ad sub-

pedales) basi sessili in caulem decurrentibus oblongis plurilobulato-dentatis. — Soledad, near Monclova, Northern Mexico, *Palmer*, 733.

To the same group, although some of them are shrubby, belong *V. gigantea*, Jacq. (which Ghiesbreght collected in Chiapas, although Hemsley does not give it as Mexican), *V. pinnatifida*, Cav. (to which belongs *V. microcephala* of Schultz Bip. and Liebman, can it be also of Benth.?), *V. serrata*, Cav., *V. pauciflora*, Hemsley, which is unknown to me, *V. sororia*, Gray, and a somewhat different set of species, such as *V. virgata*, Cav. (to which *V. persicæfolia*, DC., may be suspected to belong), *V. salicifolia*, HBK. (to which and not to the preceding Bourgeau's no. 963 should be referred, it being the same as Schaffner's plant from Tacubaya, also Parry & Palmer's no. 457, which has been confounded with *V. persicæfolia*, DC.), *V. Grayi*, Benth. & Hook., according to Hemsley, and others with which I am little or not at all acquainted.

§ 2. PTEROPHYTON, Torr. & Gray. Capitula latiora, aut solitaria aut sparsa: involucrum imbricatum (nec foliaceum, nec laxe patens): receptaculum convexum vel conicum: discus fructifer haud squarrosus: ligulæ aut neutræ, aut sæpius styliferæ sed steriles, rarius fertiles: aristæ dum adsint rectæ. — *Pterophyton*, Cass. & *Actinomeris*, Nutt., pro parte.

To this, rather than to a separate and ill-definable section, I should refer various species which have not winged stems, even if they should have fertile ray-flowers. The U. S. species with naked stems are, —

V. LONGIFOLIA, *Actinomeris longifolia*, Gray, Pl. Wright. ii. 89, a peculiar species thus far confined to Arizona. The involucre is disposed to be foliaceous-bracted.

V. WRIGHTII, *Actinomeris Wrightii*, Gray, Pl. Fendl. 85; Rothrock in Wheeler Rep. t. 8. Texas to Arizona, and recently collected by Palmer in Mexico.

V. WAREI, *Actinomeris pauciflora*, Nutt., of Florida. There is a Mexican *V. pauciflora* of Hemsley.

V. NUDICAULIS. *Helianthus ? aristatus*, Ell. Sk. ii. 428. *Actinomeris nudicaulis*, Nutt. Trans. Am. Phil. Soc. S. Atlantic States.

Of the wing-stemmed species, or *Pterophyton* proper, there are only two U. S. species known, viz.: —

V. HETEROPHYLLA, *Actinomeris heterophylla*, Chapm. in Coult. Bot. Gazette, iii. 6; native of Florida, most related to the preceding.

V. HELIANTHOIDES, Michx., *Actinomeris helianthoides*, Nutt.; from Ohio to Texas.

Wing-stemmed Mexican species known to me are, —

V. OVATA, *Coreopsis ovata*, Cav. Ic. t. 280, mentioned under *Actinomeris* by Nuttall, taken up by DeCandolle, and seemingly known to recent botanists only by Coulter's no. 362, which is described by Hemsley. It is more polycephalous than the figure, and the leaves of both specimens and figure are oblong, not ovate.

V. TETRAPTERA. *Coreopsis alata*, Cav. Ic. iii. t. 260. *Helianthus tetrapterus*, Ortega, Dec. vi. 74. *Pterophyton alatum*, Cass. xliv. 49. *Actinomeris tetraptera* and probably also *A. tetragona*, DC. Prodr. *V. scabra*, Benth. Pl. Hartw. 41, is said to belong here.

V. COULTERI. Bipedalis e radice perenni, pube molli cinerea; caule inferne foliato alato superne gracili longe pedunculiformi mono-oligo-cephalo; foliis plerisque oppositis obovatis vel spathulatis subserratis supra puberulo-scabridis subtus canescentibus, summis bracteiformibus minimis linearibus; capitulo hemisphærico lin. 3 alto; involucri bracteis biseriatis lanceolatis æquilongis; ligulis circa 12 oblongis styliferis, tubo etiam corollis disci hirsutissimo; ovariis pilosis biaristatis. — Zimapan, Mexico, *Coulter*, 341, 369.

V. CAPITANEJA, Nees in Linnæa, xix. 729. *Actinomeris pedunculosa*, DC. Prodr. v. 576; a somewhat common species. The popular name "Capitaneja," according to Schaffner, is applied to *V. tetraptera*, probably to other species.

V. NERIIFOLIA, Hemsley, no. 528 of a collection of Ghiesbreght distributed from our herbarium, and *V. Oaxacana*, DC., which Hemsley informs us is quite different, belong to a peculiar group, perhaps to be associated with *V. hypoleuca.*

Species of Mexico known to me, of the naked-stemmed group, are, —

V. HYPOLEUCA, Gray, Proc. Am. Acad. xx. 37.

V. STRICTA. *Actinomeris stricta*, Hemsl. Biol. Centr.-Am. Bot. ii. 186. The ray-flowers are not rarely styliferous and even form akenes, but wingless and probably infertile ones. Besides the collections cited by Hemsley, this is Schaffner's 343, also Palmer's 627, 628.

A peculiar species from the Mexican dominion is, —

V. VENOSA, E. L. Greene in litt. Fruticosa, fere glabra et lævis; ramis immarginatis; foliis oppositis alternisque chartaceis ovatis et ovato-lanceolatis cuspidato-acutis subintegerrimis triplinerviis reticulato-venosis utrinque viridibus minutissime scabridis basi in petiolum marginatum subito contractis; capitulis pauciusculis laxe cymoso-paniculatis; involucro campanulato lin. 3 alto disco breviore, bracteis oblongis lanceolatisque adpresso-imbricatis triseriatis, exterioribus bre-

vioribus herbaceis; receptaculo subplano; ligulis pauciusculis parvulis; acheniis obovatis subpilosis aut anguste aut latiuscule alatis aristis 2 gracilibus parum longioribus. — Cedros (miscalled Cerros) Islands, off Lower California; spec. in herb. Calif. Acad., the collector unknown.

§ 3. XIMINESIA. Capitula (sparsa) lata, disco subplano: involucrum laxe patens, e bracteis linearibus foliaceis: ligulæ plures, majusculæ, fertiles: cæt. præcedentis.

V. ENCELIOIDES, Benth. & Hook. l. c. ex Hemsley, l. c. *Ximinesia encelioides*, Cav. Ic. ii. 60, t. 178. A familiar Mexican species, now widely disseminated.

V. COAHUILENSIS. Adsurgens e radice perenni, pedalis; caulibus foliosis subramosis hirsutis; foliis discoloribus (supra hirto-pubescentibus subtus tomento albido canescentibus) lato-lanceolatis repando- nunc argute serratis basi parum angustata sessilibus plerisque secus caulem alato-decurrentibus; capitulis paucis (lin. 4–5 altis); involucro subcampanulato e bracteis linearibus foliaceis æqualibus sursum patentibus; ligulis 8–10 linearibus fœmineis fertilibus; disco convexo; acheniis parvulis hirsutis ut videtur omnibus exalatis aristis gracillimis haud longioribus, vel in radio arista altera dimidio breviore. — Mountains six miles east of Saltillo, Coahuila, *Palmer*, 584, 619. Species apparently allied to *V. mollis*, HBK., and intermediate between the *Ximinesia* and *Pterophyton* sections.

§ 4. HAMULIUM, DC. Capitulum (longe pedunculatum sæpius solitarium) latum, hemisphæricum: involucrum breve: ligulæ plurimæ disco breviores, fertiles: achenia 1–2-aristata, aristis gracilibus, uno alterove apice hamato. Cæt. fere § 2.

V. ALATA, L., *Hamulium alatum*, Cass. Dict. xx. 261; said to be Mexican as well as W. Indian.

V. ANCISTROPHORA. *Ancistrophora Wrightii*, Gray, Mem. Am. Acad. n. ser. vi. 457. *Hamulium Wrightii*, Schultz Bip. *Verbesina Wrightii*, Griseb. Cat. Cub. 155. A delicate and stemless Bellis-like little annual, of Cuba, the original specific name of which is superseded by the Texan plant formerly referred to *Actinomeris*.

§ 5. PLATYPTERIS, DC. excl. § 2. Capitula hemispherica, magna vel majuscula, radio deficiente homogama; floribus disci numerosissimis croceis: involucrum imbricatum pluriseriale: receptaculi paleæ angustæ, carinatæ, carina pl. m. hispidulo-ciliata: folia opposita, secus caulem alato-decurrentia.

V. CROCATA, Less., DC., cum syn.

V. FRASERI, Hemsl. Biol. Centr.-Am. Bot. ii. 187, t. 48. Near to

the following, which, taken up by the name only from a specimen in the Kew herbarium, should have its publication completed by a character.

V. ovatifolia, Gray, ex Hemsl. l. c. 189. "Herba fruticiformis 8–10-pedali" ex inventore, scabrida; foliis ovatis acutis subsessilibus denticulatis; capitulis subcymosis brevi-pedunculatis semipollicem altis; involucri bracteis parvulis ovatis oblongisque adpressis; corollis parce hirsutulis; acheniis immaturis oblongis; aristis subulatis basi alæ accretis. — Chiapas, S. Mexico, coll. *Ghiesbreght*, 523.

Coreopsis anthemoides, DC., is a not uncommon Mexican species, which very closely imitates *Bidens daucifolia* and *B. ferulæfolia* on a small scale, only wanting the awns. I have it not with mature akenes. It is Bourgeau's 836, and Coulter's 378, which are doubtfully referred here by Hemsley. And Schultz sent it to us, from an old collection by Schaffner, under two unpublished names, viz. *Bidens Coreopsidis* and *B. Schaffneri*. The keeping up of the two genera, *Bidens* and *Coreopsis*, necessitates a wholly artificial division of the connecting forms.

Coreopsis Schaffneri. *Eucoreopsis, Diodonta*, facie *Bidentis angustissimæ*, glaberrima; caulibus herbaceis e radice perenni 2–3-pedalibus ramosis gracilibus; foliis angustissime linearibus integerrimis aliis integris aliis tripartitis; capitulis parvulis corymboso-paniculatis; involucro ima basi pubescente, bracteis glabris subæquilongis, exterioribus angusto-linearibus laxis, interioribus lanceolatis; ligulis aureis subintegris lin. 4 longis; acheniis sublinearibus basi attenuatis lin. 3 longis biaristulatis, aristis fere lævibus vix lineam longis, demum quandoque deciduis. — Mexico, near San Luis Potosi, *Schaffner*, 202, *Parry & Palmer*, 448, 448½.

Electra, DC., it were better to retain as a genus, thus excluding all fertile- or even styliferous-rayed species from *Coreopsis*. But if not kept up, it would rather be an aberrant *Leptosyne* (wanting the annulus to disk-corolla), a genus which takes in all the other styliferous *Coreopsides* of the Genera Plantarum, and also *Coreocarpus*, Benth. Its section *Pugiopappus* (*Agarista*, DC.) comes down to two species, *L. calliopsidea*, with a var. *nana*, and *L. Bigelovii*, the *P. Breweri* being only a form of the latter.

Bidens heterophylla, Ort. This includes *B. longifolia*, DC., as well as *B. arguta*, HBK., referred here by Hemsley. Palmer's specimens (634), collected at Parras, are very like Berlandier's. To Hemsley's references may be added 363 of Bourgeau, 384 of Schaffner, and 717 of Berlandier. A genuine form, collected by Pringle in Arizona, appears to connect with this species the singular variety

(*Wrightii*) of Pl. Wright. ii. 90, which we have also from Rothrock and from Lemmon.

BIDENS LEUCANTHA, Willd. This, the *Coreopsis leucanthema*, L. Amœn. Acad., *C. leucantha*, L. Spec. ed. 2, 1282 (Desc. Fl. Ant. t. 583), and the *C. coronata*, L. as to Plumier's plant, I take to be quite distinct from the radiate form of *B. pilosa*. The *B. striata*, Sweet, Brit. Fl. Gard. t. 237, represents a large-rayed form of it.

BIDENS DONDIÆFOLIA, Less. To this must belong no. 551 of Ghiesbreght's Chiapas collection, perhaps also 569 and 570.

BIDENS PROCERA, Don in Bot. Reg. t. 684. An older and surer name for the plant which I had in Pl. Wright. referred to *B. fœniculifolia*, DC., probably correctly. It is known by its annual root, head of numerous short and (for the section) broadish akenes (outer cuneate-oblong and only 2 lines long, inner cuneate-linear and 3 lines long), not overtopping the disk, as in its allies, and the rather long and conspicuously barbed awns. Hemsley has confounded it with the similar perennial species, *B. ferulæfolia*, DC., *Coreopsis ferulæfolia*, Jacq. Hort. Schœnb. t. 375, and Bot. Mag. t. 2059, which I take to be the species still cultivated in the gardens in a low form, and which has the narrow linear akenes of the section, and short inconspicuously barbed awns. But the fruit is not described by Jacquin, nor in the Bot. Magazine. To *C. procera*, the annual species, I refer Schaffner's no. 231. Bourgeau's 502, and perhaps Gregg's 397, which has no fruit, nor root. To *B. ferulæfolia*, Bourgeau's 954½. and 85 and 533 of Ghiesbreght's collection.

Allied to *B. ferulæfolia* are *B. daucifolia*, DC. (if no. 1117 of Parry and Palmer's collection is that species), and *B. caucalidea*, DC. (to which Parry and Palmer's 484 has been referred); perhaps also the *Cosmos chrysanthemifolius*, HBK. t. 382, which is certainly a *Bidens*, and which should be re-examined at Berlin, to ascertain if it may not have had yellow ligules. In that case, as the habitat "Nova Hispania" is given with a query, this may be *Bidens humilis*, HBK.

"BIDENS SEEMANNI," Schultz Bip. in Seem. Bot. Herald, 307. To this has been wrongly referred no. 485 of Parry and Palmer's Mexican collection, which seems to be only *Cosmos crithmifolius*, HBK. But there is a plant of an early collection by Ghiesbreght, no. 264, which may be it (if so, *Cosmos Seemanni*), having filiform divisions to its leaves, and essentially beakless 6-awned akenes. *Cosmos tenuifolius*, Lindl. Bot. Reg. t. 2007, is only *C. bipinnatus*, Cav.

THELESPERMA AMBIGUUM. This name is assigned to the radiate species which replaces *T. filifolium* in the western part of Texas and

adjacent parts of New Mexico and Colorado. It has been confounded sometimes with *T. filifolium*, sometimes with *T. subsimplicifolium*. From the former it is distinguished by a more rigid habit, coarser and less dissected foliage, and by being truly perennial, spreading by creeping rootstocks. The latter goes into a section containing also *T. subnudum* and *T. longipes*, well characterized by short corolla-lobes and a rudimentary or obsolete pappus.

Madieæ.

HEMIZONIA PANICULATA. *H. floribundæ* sat affinis; caule inferne hirsuto; foliis caulinis plerisque pinnatifidis, ramealibus integerrimis linearibus parvis; capitulis laxe paniculatis ramulos bracteolatos terminantibus; ligulis 8; bracteis receptaculi aut fere discretis aut ultra medium connatis; floribus disci 10–12; acheniis radii scrobiculato-pauci-rugosis, rostro brevi arrecto; disci haud raro fertilibus pappo 8–10-paleato, paleis subcoriaceis oblongis obtusis extus marginibusque hirsutis tubo proprio corollæ longioribus. — Santa Barbara to San Diego Co., California, *Brewer*, *Parish*, *Jared*. Includes the plant of coll. Brewer which was referred to *H. angustifolia* var. *Barclayi* in the Botany of California.

HEMIZONIA WRIGHTII. Præcedenti affinis, inter *H. Kelloggii*, Greene, et *H. fasciculatam* collocanda, aut erecta 1–3-pedalis ramis patentissimis, aut decumbens ramosissima; foliis inferioribus laciniato-pinnatifidis hirsutis, ramulinis parvis cum pedunculis bracteisque involucri ovato-lanceolatis; floribus radii sæpius 5, ligulis lato-cuneatis, acheniis subtuberculato-rugosis brevi-rostellatis; floribus disci 5–6 bracteis receptaculi pl. m. connatis circumdatis sterilibus, pappo e paleis 8–9 oblongis sat robustis apice eroso-laciniatis. — California, common in the vicinity of San Bernardino, first coll. by *W. G. Wright*, then by the brothers *Parish* and by *Parry*, also as a waif near San Francisco, *Greene*, probably conveyed by railway.

LAYIA (CALLIGLOSSA) DOUGLASII, Hook. & Arn. Bot. Beech. 358. This obscure species, so long known only from the single specimen collected by Douglas near the Great Falls of the Columbia River, has at length come to light in the collection of *Marcus E. Jones*, in 1882. He found it at Austin, Nevada. In aspect and in the white rays it resembles a small form of *L. glandulosa*; and it has a few small stipitate glands on the involucre and the uppermost leaves. It is well marked by the pappus, which consists of about 10 linear-subulate flat awns, the margins of which toward the base bear a moderate number of long and straight villous hairs. It is white; the fulvous tinge in

that of the original specimen was probably from discoloration. — To Mr. Jones we are likewise indebted for the following addition to the *Calliachyris* group of the *Calliglossa* section.

LAYIA JONESII. *L. Fremonti* peraffinis, parce hispidula, viscida, superne glandulis parvis stipitatis parce conspersa; foliis pinnatifidis vel superioribus tridentatis nunc integerrimis; ligulis breviusculis; bracteis receptaculi tantum ad marginem; pappo e paleis ovatis seu ovato-oblongis acuminato-acutatis erosulo-denticulatis nudis corollæ tubo haud longioribus. — California, near San Luis Obispo, *M. E. Jones*. — Forms like these, distinguished almost wholly by the pappus, have to be noticed and characterized; but they weaken the value of the species in this genus.

Helenioideæ.

CLAPPIA SUÆDÆFOLIA, Gray in Bot. Mex. Bound. 93. This has been rediscovered by Dr. Havard, U. S. A., on the alkaline flats toward the mouth of the Pecos River, in the southwestern part of Texas. A good specimen received from him shows that the plant is an undershrub; that the linear leaves are so fleshy as to be terete, and are neither punctate nor at all glandular; so that the genus must be excluded from the *Tagetineæ*. It may rest in the somewhat artificial subtribe *Jaumieæ* of Bentham and Hooker. But the genus consists solely of the original species, which, considering the state of the materials, has been well figured by Bentham in the Icones Plantarum, t. 1105. The supposed second species, *C. aurantiaca*, Benth. Ic. Pl. t. 1104, is very different, and if not *Dysodia appendiculata*, Lag., with the oil-glands overlooked or wanting in the specimen, must be very nearly related to that species.

LAPHAMIA and PERITYLE. A new study of all the species confirms our conclusion (in Proc. Am. Acad. ix. 194), that these nearly related genera should be preserved with their original limitation, rather than that suggested by Bentham in the Genera Plantarum. The pappus gives better characters than the style-appendages, and there is no good distinction to be found in the involucre.

LAPHAMIA divides into three sections: — 1. PAPPOTHRIX, for *L. rupestris* and *L. cinerea*. 2. True LAPHAMIA, for *L. Lemmoni* and its var. *pedata*, *L. halimifolia*, *L. angustifolia* and its var. *laciniata*, *L. Palmeri*, with flowers said to be "creamy-white," *L. megacephala*, Watson, and *L. Stansburii*. 3. DITHRIX, with a pair of stouter naked bristles, one from each angle of the akene, and the head only 6–8-flowered, *L. bisetosa*, Torr.

PERITYLE makes the closest approach to the foregoing genus in *P. dissecta* (*Laphamia dissecta*, Torr. in Pl. Wright. ii. 81), the akene of which is hardly ciliate, and the crown of the pappus is reduced to a mere border, the single awn sometimes wanting. The style-branches are slender and subulate, not "short and obtuse," as was stated in Proc. Am. Acad. ix. 195. Among the genuine species, *P. Fitchii*, Torr. in Pacif. R. Rep. iv. 100, founded on imperfect materials, probably from the islands off California, appears to include (as var. *Palmeri*) the plant collected by Palmer on Guadalupe Island, no. 44, and distributed as *P. Emoryi*. It has thin-edged akenes, nearly hirsute-ciliate, and somewhat falcately oblique; the pappus sometimes obsolete, sometimes of numerous squamellæ united into an erose crown, and no awn. Otherwise it is hardly distinguishable from *P. Californica*, Benth. (of the section having callous-margined akenes densely long-ciliate), which proves to be the *P. Emoryi*, Torr., including var. *nuda*, the *P. nuda*, Torr. *P. plumigera* is still known only from Coulter's specimens. *P. microglossa*, Benth., which had been overlooked, is the *P. Californica* of Gray, Proc. Am. Acad., &c. (but not of Benth.), and *P. Acmella*, Gray, Pl. Fendl. 77, &c. There is a marked var. *effusa*, very much branched and paniculately floriferous, with unusually small heads and akenes, from Arizona, *Pringle*. *P. leptoglossa*, *P. Parryi*, and *P. aglossa* remain as rare but seemingly good species, all with setaceous-filiform style-tips.

EATONELLA, Gen. Nov. Subtrib. *Peritylearum*.

Capitulum circiter 20-florum, heterogamum, floribus radii fœmineis, ligulis parvulis, vel radio deficiente homogamum. Receptaculum planum nudum. Involucrum e bracteis planis 5–8 ovalibus oblongisve æqualibus. Corollæ disci breviusculæ, superne dilatata 4–5-dentatæ. Styli rami fl. disci breves truncato-obtusi. Achenia compressa (extima nunc obcompresso-triangulata), calloso-marginata, crebre ac longissime villoso-ciliata. Pappus e paleis paucis sæpius 2 latissimis enerviis. — Herbæ annuæ vel biennes, Californicæ, lanosæ, alternifoliæ, capitulis parvulis subsessilibus. Species 2.

EATONELLA NIVEA. Pygmæa, vix caulescens, laxe lanosissima; capitulis inter folia rosulato-conferta spathulata integerrima sessilibus; involucri bracteis 8 angusto-oblongis; ligulis totidem parum exsertis; corollis disci 5-dentatis; acheniis lineari-oblongis atro-nitidis coma niveo-alba ciliatis; pappi paleis 2 opacis latissimis subtruncatis parce eroso-dentatis e centro in aristam longiorem subulatam productis. — *Burrielia nivea*, D. C. Eaton in Bot. King Exp. 174, t. 18. *Acti-*

nolepis? (*Eatonella*) *nivea*, Gray, Bot. Calif. i. 379. — Eastern side of the Sierra Nevada, *Watson*, *Lemmon*.

EATONELLA CONGDONI. Floccoso-lanata; caulibus ultraspithamæis; foliis sparsis oblongo-linearious sæpe sinuato-dentatis vel repandis; involucri bracteis 5 lato-oblongis; ligulis ut videtur nullis; corollis disci 4-dentatis; acheniis ovalibus faciebus pubescentibus mox glabratis, extimis triquetro-obcompressis, cæteris plano-compressis; pappo villum achenii haud superante, paleis paucis diaphanis eroso-laciniatis muticis. — Deer Creek, Tulare Co., California, *J. W. Congdon*, and southern part of the San Joaquin Valley, *Parry*.

The suggestion that the original species was of a new genus being now confirmed by the discovery of a second species, though of somewhat different habit, the genus is now characterized, and named in honor of Professor Daniel Cady Eaton of Yale College, who elaborated the Compositæ of Mr. S. Watson's collection in King's expedition along the fortieth parallel, in the published report of which *E. nivea* is described and figured, and its peculiarities indicated. One would wish that the name of our most accomplished pteridologist should be associated with a new genus of Ferns, but such are not met with. We must be content with a genus of the order which, next to Ferns, he has most studied, and the type of which he has himself illustrated. Although the habit and other characters are of the *Bahia* group, the achenia refer it to the subtribe *Peritylææ*.

MONOLOPIA GRACILENS. E grege *M. majoris*, multum tenuior, paniculatim ramosa; foliis linearibus vel lanceolatis; involucri parvuli (¼-pollicaris) bracteis 8 ad basim usque discretis; acheniis glabratis. — Coast Range of California, near New Almaden and Santa Cruz, *Torrey*, 1865, and later collected by *S. G. Isaman* (received from Prof. Bailey), *Bolander*, and *Pringle*.

SYNTRICHOPAPPUS LEMMONI. Nana, gracilis, lana laxa mox decidua; foliis spathulatis seu linearibus integerrimis; involucri bracteis 6 vel 8 angusto-oblongis; ligulis parvulis roseo-albis; corollis disci luteis; pappo nullo. — *Actinolepis Lemmoni*, Gray, Proc. Am. Acad. xvi. 102. — S. E. California, on the Mohave Desert, *Lemmon*. Summit of Cajon Pass, *Parish*. — This little plant is found to have the very short proper tube and elongated throat of the corolla and the asteroid style-branches of *Syntrichopappus*. So that, in the readjustment of the related forms, this is left to go into the latter genus, notwithstanding the absence of pappus.

BAERIA, Fisch. & Meyer, as extended by Bentham in the Gen. Plantarum (*Burrielia* excluded chiefly on account of its slender style-

appendages), and adopted in the Botany of California, we must now extend so as to take in *Ptilomeris*, which certainly cannot go with *Actinolepis*. As to the carination and internal saccation or folding of the involucral bracts along the axis or at base, partially embracing a subtended akene, this is quite as distinctly seen in Nuttall's *Dichæta*, and there are traces of it in the typical species of *Baeria*. Some additional species having recently been recognized, a key to those now known is appended.*

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* BAERIA, Fisch. & Meyer, extended.

§ 1. EUBAERIA. Pappus when present uniform (rarely unequal), of entire paleæ or paleaceous-based awns: leaves entire except in *B. platycarpha*: ligules well exserted.

* Akenes with convex or narrowed summit and therefore comparatively small areola, mostly glabrous or glandular and papillose: pappus aristiform or commonly none: heads comparatively large. — *Baeria*, Fisch. & Meyer.

B. MACRANTHA. At least sometimes perennial (all others are annual), rather stout; leaves somewhat 3-nerved and obtuse, hispidly ciliate below; involucral bracts about 12, thickish-herbaceous; ligules elongated; pappus mostly none. — *B. chrysostoma*, var. *macrantha*, Gray, Proc. Am. Acad. ix. 196, and Bot. Calif. *Burrielia chrysostoma*, var. *macrantha*, Gray in Pacif. R. Rep. iv. 106. — Var. PAUCIARISTATA. Lower, clearly perennial, leafy only toward base; rays shorter; akenes scabrous with acute conical papillæ; pappus not rarely present, of 1, 2, or sometimes 3 subulate and flattened chaffy awns rather than paleæ, ather shorter than the akene. — Mendocino Co., *Bolander*, *Pringle*.

B. CHRYSOSTOMA, Fisch. & Meyer. Bracts of involucre 7 to 12, or fewer in depauperate specimens; linear-clavate akenes either wholly smooth or sprinkled with glandular atoms and papillæ; pappus always wanting.

* * Akenes with broader and truncate summit, usually bearing a paleaceous and mostly awned pappus (but this occasionally wanting, perhaps in every species), more or less hispidulous and 4-angled, not glandular.

+- Involucre and commonly herbage hirsute-pubescent, the leaves mostly hirsute-ciliate toward base: plants slender, very variable in size according to season and station.

B. GRACILIS, Gray, l. c. Bracts of involucre and rays 10 to 12 or reduced to 5 or 6; pappus when present of 2 to 5 awned paleæ (the smaller number usually in the ray), which about equal the length of the akene. — *Burrielia gracilis* and *B. tenerrima*, DC. Prodr. *B. hirsuta*, Nutt., a form which wants the pappus. The original of Douglas has 3 or 4 small lanceolate paleæ of the pappus tapering gradually into the slender awn; it therefore approaches the extreme form in that direction, i. e. Var. ARISTOSA, in which the awn is very gradually and inconspicuously widened downward, as represented by *Burrielia gracilis*, Hook. Bot. Mag. t. 3758. The opposite extreme is Var. PALEACEA, with awns abruptly dilated at base into an oval or ovate palea. This is *Burrielia longifolia* and *B. parviflora*, Nutt. l. c.

B. CURTA. Heads only 2 or 3 lines high; bracts and rays 8 or 10; pappus of

Bahia and Eriophyllum, Lagasca. These appear to be two well-recognizable genera, as DeCandolle suspected, although he was unable

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ovate or oblong pointless paleæ, not exceeding the breadth of the akene, usually 4 or 5, or in ray-flowers reduced to a single one, in some plants all obsolete. — S. E. California, near San Bernardino, *W. G. Wright*, *Lemmon*, the latter with obsolete or unipaleaceous pappus.

+- +- Involucre and whole herbage either glabrous or minutely soft-pubescent, no hirsute hairs: heads middle-sized: pappus of firm ovate paleæ abruptly attenuate into an awn, the whole as long as the akene: leaves rather fleshy,

++ Narrowly linear, quite entire.

B. carnosa, Greene in litt. Stem with some minute tomentulose pubescence, glabrate; bracts of the involucre about 7, oblong, obtuse, thickish-herbaceous, smooth, at maturity carinate, having a very strong and salient midnerve and an obscure distant lateral pair; rays oblong; akenes densely hispidulous-canescent; pappus-paleæ 4, rarely 5, subulate-awned. — Salt marsh at Vallejo, on the Bay of San Francisco, *E. L. Greene*, April, 1883.

B. Clevelandi. Branches and peduncles slightly pubescent; bracts of involucre 8 to 12, ovate, rather obtuse, with one or three obscure nerves at base; rays oval; young akenes minutely scabro-hispidulous; paleæ of pappus slender-awned, only 2 in disk and ray. — Near San Diego, *Cleveland*, 1874.

++ ++ Nearly filiform leaves 3–5-parted or some entire.

B. platycarpha, Gray, l. c. Slightly pubescent throughout; bracts of involucre 6 or 7, ovate, acutish, lightly and about equally 3-nerved at base; rays narrowly oblong; paleæ of pappus slender-awned, 6 or 7 both in ray and disk. — Thus far received only from the valley of the Sacramento, station unknown, coll. by *Stillman*.

§ 2. Dichæta. (*Dichæta*, Nutt.) Pappus (occasionally wanting) of two forms,

* Unlike in disk and ray, in both of about 5 fimbriate-laciniate paleæ, in the former awned, in the latter mostly muticous: leaves entire.

B. Palmeri, Gray, Bot. Calif. i. 376, is only of Guadalupe Island off Lower California, *Palmer*.

* * Not unlike in disk and ray, composed in both of truncate or muticous short paleæ between 2 or 3 awned ones or naked awns.

+- Rays hardly exserted: leaves all entire: pappus of 3 to 5 awns and at least twice as many squamellate narrow laciniate paleæ.

B. maritima, Gray. Farralones Islands. Should be collected anew.

+- +- Rays usually exserted: pappus sometimes wanting: some of the leaves laciniate or pinnatifid: involucral bracts of the next section. — *Dichæta*, Nutt.

B. Fremonti, Gray. Leaves slender; pappus of 4 slender awns and of narrow entire or 2-cleft small paleæ.

B. uliginosa, Gray. Leaves linear or broader, the lower once or twice pinnatifid; pappus of 2 or sometimes 3 chaffy awns and of broad truncate laciniate paleæ. — *Dichæta uliginosa*, Nutt. l. c.

Var. tenera. Smaller form on drier soil, not rarely leaves all entire; paleæ

to fix the characters, and as Nuttall was assured, although he unwittingly suppressed the former genus by founding his genus *Stylesia* upon Lagasca's original *Bahia*. *Bahia oppositifolia* is the only species which approaches *Eriophyllum*, and it has the distinguishing characters of *Bahia*. These are, the comparatively lax involucre, open in fruit (or even reflexed when the akenes have fallen), composed of herbaceous or submembranaceous bracts, always distinct and commonly narrowed at base; a small receptacle; and paleæ of the pappus with callous-thickened base or costa: no species is floccose-lanate, although one is canescent-tomentulose. *Eriophyllum* has an erect cupuliform involucre, which does not spread in fruiting, is not rarely gamophyllous at base and sometimes to above the middle, and generally coriaceous rather than herbaceous; the receptacle varies from

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often united into 2 quadrate scales between the two awns. — *Dichæta tenella*, Nutt. l. c.

§ 3. Ptilomeris. Pappus (in one species wanting) of several similar or not very dissimilar paleæ, awned or pointed from the summit or muticous, commonly erose: receptacle not muricate-roughened by the persistent supports to the akenes, as in the preceding sections: bracts of the involucre more or less carinate-saccate at the middle of base, when mature somewhat embracing the subtended akene, at length deciduous with it: leaves all 1–2-pinnately parted into narrow linear or filiform divisions. — *Ptilomeris*, Nutt. Trans. Am. Phil. Soc. vii. 382. *Actinolepis* in part, Benth. & Hook. Gen.

* Rays 6 or 8, oblong, short-exserted: involucral bracts broad: receptacle glabrous, either acutely or obtusely conical: heads small (barely 3 lines high): plants a span high, minutely pubescent, but hardly at all glandular.

B. affinis. Pappus of 8 or 10 oblong or lanceolate paleæ, with laciniate-setulose margins, some or most of them produced into an awn which almost equals the disk-corolla, or in the ray muticous and awnless. — *Ptilomeris affinis*, Nutt. Pl. Gamb. 174. — Lately collected anew, at Los Angeles and San Bernardino, by *Nevin* and *Parish*; probably may hold, as distinct from the next.

B. tenella. Pappus of 6 to 8 short and firm quadrate or broadly cuneate paleæ, the truncate summit denticulate or nearly entire, not surpassing the tube of the corolla. — *Ptilomeris tenella*, Nutt. Pl. Gamb. 173. *Actinolepis* (*Ptilomeris*) *tenella*, Gray, Bot. Calif., mainly. Recently again collected, at Los Angeles, by *Parry*.

* * Rays 10 to 15, elongated-oblong, exserted: involucral bracts oblong-lanceolate: receptacle minutely and sparsely pubescent, acutely conical: plants minutely glandular-pubescent, a span to a foot high, diffuse: perhaps both varieties of one, differing mainly in the pappus.

B. coronaria. *Ptilomeris coronaria*, Nutt. l. c. *Hymenoxys Californica*, Hook. Bot. Mag. t. 3828. *Actinolepis coronaria*, Gray, Bot. Calif., with syn. — Pappus of awn-pointed paleæ.

B. mutica. *Ptilomeris mutica*, Nutt. l. c. *Actinolepis mutica*, Gray, Bot. Calif. l. c., with syn. — Pappus of quadrate-oblong obtuse or truncate paleæ.

plane to conical, and the pappus-paleæ are not costate; all the species are floccose-lanate, and all are restricted to one phyto-geographical region. Moreover, the involucral bracts (as had been remarked in the Botany of California, and is now confirmed in all the species) become carinate-concave at their centre, or where narrow (as in *Eriophyllum stæchadifolium*) wholly concave around the subtended ray-akenes, just in the manner of *Actinolepis*, where it was pointed out by Nuttall and by Bentham. It is thus seen that *Eriophyllum* should include *Actinolepis*, DC., yet not *Ptilomeris*, Nutt. And *Bahia* equally includes *Achyropappus*, HBK., to the great relief of the genus *Schkuhria*, which may thus resume its natural proportions and character. A survey of the species will show that while a costa to the pappus-paleæ, or some equivalent basal thickening, is characteristic of *Bahia*, the extent of its development and even its emergence at the apex are of no consequence. In *Bahia? nepetæfolia*, Gray, Proc. Am. Acad. v. 184, which Schultz has identified with *B. sinuata*, Less., the larger paleæ are costate-thickened to the apex, but some of the short ones not perceptibly so even at their base. In both these genera, as in other *Helenieæ*, the pappus is occasionally obsolete or wanting. It is uniformly wanting in *B. chrysanthemoides*, which I wrongly referred to *Villanova*, and was followed by Bentham. But *Villanova* has broad and triangular or triquetrous or obcompressed as well as calvous akenes, the truncate apex with small areola, the lateral angles in the ray commonly margined, sometimes tuberculate-thickened. Under these views the three genera of Lagasca, and the older *Schkuhria* of Roth, become definite, intelligible, and natural. The species, as thus rearranged, are as follows.*

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* ERIOPHYLLUM, Lag.

Neither at Madrid nor in Boissier's herbarium could I obtain any information as to Lagasca's two species of this genus, which in all probability is equivalent to Nuttall's *Trichophyllum*, published two or three years later. But his *E. stæchadifolium* is fairly well made out. Even *E. trolliifolium*, though not identified, may be of the genus, for one or two of the following species sometimes have purple or rose-colored ray-flowers. Our species are these: —

§ 1. Actinolepis. — *Actinolepis*, DC., Benth. & Hook. Gen. ii. 399, excl. *Ptilomeris*. All annuals and low.

* Heads sessile or nearly so in the forks of the at length much-branched stems or at the summit of the branches, where they are glomerate or leaf-subtended, 2 lines high, yellow-flowered: receptacle flat or barely convex: anther-tips ovate-lanceolate, obtuse: leaves spatulate, commonly 3-lobed or toothed at the summit.

E. multicaule. — *Actinolepis multicaulis*, DC.; Hook. Ic. t. 325; Torr. Bot.

AMBLYOPAPPUS, Hook. & Arn. (*Aromia*, Nutt., *Infantea*, Remy), is near to *Bahia*. It is distinguished mainly by the reduction of the

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Mex. Bound. t. 33. The species was founded on a form, hardly since collected, with most of the disk-flowers infertile, and with their style almost entire.

E. PRINGLEI. Depressed, an inch or two high, flowering from near the base, and forming tufts, loosely and copiously woolly; rays none; flowers all fertile; akenes villous; pappus of about 10 silvery-scarious and oblong-lanceolate pointless paleæ, of rather large size.—On gravelly plains, from the Mohave Desert to Tucson, Arizona, first coll. by *Palmer*, then by *Lemmon*, and recently by *Pringle* and *Parish*. Overlooked until lately in the herbarium, having been confounded with the common pappose variety of *E. multicaule*, and as such distributed by Mr. Pringle.

* * Heads larger (3 or 4 lines high), pedunculate, terminating open branches: rays 5 to 9, oval or oblong, exserted: anther-tips narrow and slender (in the manner of *Burrielia*): receptacle low-conical or high-convex: leaves mostly entire: larger plants 4 or 5 inches high, some species diffuse.

+ Rays about 5, small and inconspicuous: disk-flowers not very many: anther-tips ovate-oblong, obtuse.

E. NUBIGENUM, Greene in litt. Densely white-woolly; leaves lanceolate-spatulate; heads short-peduncled, narrow; involucre of 5 oblong bracts; rays with oval ligule hardly longer than the disk-flowers, yellow; receptacle with a small conical centre; paleæ of the pappus about 10, oblong or narrower, obtuse, somewhat erose, nerveless, obscurely hyaline, half the length of the corolla, one third the length of the akene. — On Cloud's Rest, above the Yosemite, at 9,000 feet, *K. Curran*, from *Greene*.

++ Rays 5 to 9, exserted and ample, oval or oblong: anther-tips narrow and slender: receptacle high-convex or obtusely low-conical.

E. WALLACEI. — *Bahia Wallacei* Gray, Pacif. R. Rep. iv. 105. *Actinolepis Wallacei*, Gray, Proc. Am. Acad. ix. 198; with Var. RUBELLA, a form with rose-red rays, instead of the ordinary golden yellow ones.

E. LANOSUM. — *Burrielia lanosa*, Gray, Pacif. R. Rep. l. c. *Actinolepis lanosa*, Gray, Proc. Am. Acad. l. c. Remarkable for its white or rose-colored rays.

§ 2. TRICHOPHYLLUM. — *Trichophyllum*, Nutt. Gen. ii. 166. *Phialis*, Spreng. Gen. 631, but involucre only occasionally gamophyllous. The pappus is always short, of firm and opaque nerveless and pointless paleæ, not rarely much reduced, sometimes obsolete or wholly wanting. Flowers all yellow.

* Suffruticose and cymosely polycephalous species; the head small.

E. STÆCHADIFOLIUM, Lag.— *Bahia stæchadifolia* & *B. artemisiæfolia* (Less.) DC. There is hardly a doubt that Lagasca's plant was a fragmentary specimen of this Californian coast species, with only rameal leaves, which are not rarely entire or obsoletely lobed. The "Real del Monte" of Hænke is Monterey, California.

E. CONFERTIFLORUM, *Bahia confertiflora*, DC. With two rather marked varieties. — Var. TRIFIDUM, the *Bahia trifida*, Nutt. l. c., & *B. confertiflora*, Gray, Bot. Calif. — Var. LAXIFLORUM. Like the type, but with loose or more open inflorescence, the heads mostly slender-peduncled; the rays sometimes larger. *Bahia tenuifolia*, DC. ! l. c. Coll. also by *Coulter*.

corollas, both of disk and ray; the absence of ligule to the ray-corollas (if they may be so called); by the conical receptacle; and by some

* * Herbaceous, commonly if not always perennial, with larger heads usually solitary and conspicuously pedunculate, sometimes more numerous on the branches and even cymosely disposed: recepacle from low-conical to flat, in the same species.

+ Akenes not glandular.

E. CÆSPITOSUM, Dougl. in Lindl. Bot. Reg. t. 1167; the involucre doubtless wrongly figured as gamophyllous, though this is sometimes the case. To this I am obliged to refer all the forms collected under *Bahia lanata* in the Botany of California, along with those under *B. integrifolia* and even *B. arachnoidea*, arranging them under the varieties *latifolium*, *achillæoides*, *grandiflorum*, *leucophyllum*, and *integrifolium*. A slender form is the *B. lanata*, var. *tenuifolia*, Torr. & Gray, Fl. But the *B. tenuifolia*, DC., is quite different, as the original specimen and the description show.

++ Akenes, like the corolla-tube, glandular: stems slender, low.

E. GRACILE, the *Bahia gracilis*, Hook. & Arn. This is still known only by Tolmie's specimens, from the Snake River district. It has a loose floccose wool, very narrow leaves, so far as known all entire, an involucre of about 10 oblong bracts, a nearly flat receptacle, slender akenes, the breadth of which is exceeded by the length of the pappus.

E. WATSONI, the *Bahia leucophylla*, in part, of Eaton, Bot. King Exp., wrongly joined to the preceding in Bot. California. This is canescent rather than lanate, fastigiately branched, has leaves of cuneate or spatulate outline, and 3-lobed smaller heads, an involucre of 6 or 7 oval bracts, only 5 or 7 rays, a conical receptacle, shorter and thicker akenes, and a coroniform pappus of truncate and laciniate paleæ decidedly shorter than the width of the akene.

* * * Annuals, with leaves apparently all alternate, small pedunculate heads terminating lax and slender branches, pappus a crown of very small paleæ, or wanting in some flowers, and a conspicuously conical receptacle: the bracts of the involucre are more commonly, but not always, gamophyllous.

E. AMBIGUUM. — *Bahia ambigua* and *B. parviflora*, Gray, Bot. Calif. i. 382, where the synonymy is given. The two supposed species prove to be mere forms of one.

BAHIA, Lag.

The typical species of *Bahia* are suffruticose or perennial. Those of *Achyropappus*, HBK. are annuals, one perhaps rather biennial; and this is the only tangible difference. These species are more naturally placed under a series of sections.

§ 1. Suffruticose or perennial; at least the lower leaves opposite and dissected or lobed: paleæ of the pappus destitute of a distinct costa. — True *Bahia*.

* Anomalous species, imperfectly ligulate, and with irregular very unequal pappus: leaves all opposite and sinuately lobed: flowers apparently white.

B. SINUATA, Less. in Linnæa, vi. 160. *B.* ? (*Anisostemma*) *nepetæfolia*, Gray, Proc. Am. Acad. v. 184. Mexico.

carination without and hollowing within of the axis of the involucral bracts. Weddell's *Schkuhria pusilla*, judging from the figure, must either be of this genus or a species connecting it with *Bahia*.

SCHKUHRIA, Roth. This genus, after elimination of species which belong to *Bahia*, is not so closely related to the latter genus, or to *Achyropappus*, as was supposed. It is completely characterized by its turbinate or obpyramidal involucre, of few bracts with petaloid-margined summit, very few flowers, these either homogamous, or one or two with very short ligule, truly obpyramidal akenes with four equal

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* * Genuine species: paleæ of the pappus obovate or spatulate, scarious and rounded or truncate at summit, and with a callous-thickened base.

+ Rays white: leaves all opposite, much divided.

B. AMBROSIOIDES, Lag. — Chili.

++ Rays and disk yellow. — North American.

B. OPPOSITIFOLIA, Nutt. in Torr. & Gray, Fl. *Trichophyllum oppositifolium*, Nutt. Gen. The opaque thickish base of the paleæ of the pappus extends into a kind of costa, which is evanescent below the summit.

B. ABSINTHIIFOLIA, Benth., which passes into its strongly marked variety DEALBATA. Pappus nearly that of *B. ambrosioides*.

§ 2. Herbaceous from a perennial caudex: leaves all alternate and entire, coriaceous or thickish: paleæ of the pappus about 10, linear-lanceolate, hyaline-scarious, with a distinct excurrent or percurrent costa: flowers yellow. — *Schkuhria* § *Platyschkuhria*, Gray, Proc. Am. Acad. ix. 198, & Am. Nat. viii. 213.

B. NUDICAULIS. — *Schkuhria integrifolia*, Gray, l. c. excl. var.

B. OBLONGIFOLIA. Smaller, with leafy stem, narrowly oblong leaves; pappus little shorter than the glabrate akene; its paleæ firmer, smooth, entire-edged. — *S. integrifolia*, var. *oblongifolia*, Gray, l. c.

§ 3. Annuals, the last species perhaps biennial, with palmately or pedately parted or divided leaves: akenes all narrow, quadrangular, mostly hirsute along the attenuate base. — *Achyropappus*, HBK., DC.

* Leaves mainly opposite and the divisions narrowly linear: paleæ of the pappus broad, very obtuse, scarious, with callous-thickened base not extended into a distinct costa. — True *Achyropappus*.

+ Mexican species.

B. ANTHEMOIDES, Gray, Proc. Am. Acad. xv. 40. *Achyropappus anthemoides*, HBK. Nov. Gen. & Spec. iv. 259, t. 390.

B. SCHKUHRIOIDES. — *Achyropappus schkuhrioides*, Link & Otto, Abh. Neu Gew. Gart. Berl. t. 30, 1828. *Schkuhria senecionoides*, Nee, Del. Sem. Hort. Bonn. 1831. — A close congener of the preceding, and near the following.

++ North American (Texano-Arizonian) species, which were referred to *Schkuhria* in Proc. Am. Acad. ix. 199, with the rest of *Achyropappus*.

B. BIGELOVII, Gray, Bot. Mex. Bound. 96.

B. NEO-MEXICANA. — *Schkuhria* (*Achyropappus*) *Neo-Mexicana*, Gray, Pl. Fendl.

faces, and also by the habit. The genus falls into two sections; one, equivalent to *Hopkirkia*, DC., has only 3–5-flowered heads, generally homogamous, sometimes a single ray-flower, and the akenes so broadly obpyramidal that the length is little more than double the width of the summit, the angles very densely long-villous, and the faces (also sparsely hairy) are more obviously striate-nerved at maturity: *S. Hopkirkia*, *Wislizeni*, and *Wrightii*, Gray, two of them in Arizona, the other only in Mexico.

The section including the older species has narrower akenes, mod-

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98, &c. Paleæ of the pappus thickened in centre to the middle or more. Rays none.

* * Leaves mainly opposite and with simple linear divisions: flowers with short and apparently white rays: paleæ of the pappus lanceolate, acute, and with a complete but not excurrent costa. New Mexico.

B. Woodhousei. — *Achyropappus Woodhousei*, Gray, Am. Acad. vi. 546. *Schkuhria Woodhousei*, Gray, Proc. ix. 199.

* * * Leaves mostly alternate, 2–3-ternately dissected into narrow linear lobes: stems slender, loosely branched: rays none: paleæ of the pappus oblong or broadly lanceolate, traversed by a complete costa, which in the alternate ones is produced into a short bristle or awn, the others muticous or nearly so. South American; nearest *Schkuhria*, but the flowers numerous, involucre broader, and akenes linear-clavate.

B. Gilliesii. — *Schkuhria multiflora*, Hook. & Arn. in Jour. Bot. iii. 322. *S. anthemoides*, Griseb. Pl. Lorent. 139 (*S. pusilla*, id. Symb. Argent. 199, at least in part, excl. syn., but not *S. pusilla*, Wedd. Chl. And. No. 72 of Mandon's Pl. And. Boliv. (I have not 73) is of this species or very near it, certainly is neither *B. anthemoides*, nor *Schkuhria pusilla*, Wedd., which is not a genuine *Schkuhria*, but perhaps an *Amblyopappus*.

* * * * Leaves all or mostly alternate, 2–3-ternately divided or parted, the divisions or lobes from linear-spatulate to obovate: stem simple, comparatively stout, bearing several or rather numerous somewhat corymbosely cymose many-flowered heads at the naked summit: rays conspicuous, yellow: involucre hemispherical: paleæ of the pappus (when present) with distinct costa. S. W. North American species, of closely similar aspect.

+ Pappus of 10 to 14 paleæ, with costa in some evanescent below the apex, in others excurrent: tube of the disk-corollas glandular, but not hirsute; the lobes ovate or oblong and shorter than the dilated throat. Species of *Schkuhria* § *Achyropappus*, Gray, in Proc. Am. Acad. ix. 199.

B. pedata, Gray, Pl. Wright. i. 132.

B. biternata, Gray, Pl. Wright. ii. 95.

++ Pappus none: tube of corollas viscid-hirsute: lobes of those of the disk almost equalling the throat and tube together: plant more robust, sometimes 4 feet high.

B. chrysanthemoides. — *Villanova chrysanthemoides*, Gray, Pl. Wright. ii. 96. *Amauria? dissecta*, Gray, Pl. Fendl. 104.

erately hairy or glabrate on the angles, smooth and mostly even on the face; the leaves usually more pinnate; the flowers inclined to be more numerous. As in the preceding section, the species are distinguished mainly by the pappus. Of the two Mexican species, *S. virgata*, DC., comes nearest to *S. Wislizeni*, to which belongs a plant of Galeotti from Oaxaca, which I have as no. 2049, probably an error for "2045." This number Hemsley has referred to *S. abrotanoides*. *S. Bonariensis*, Hook. & Arn., *S. octoaristata*, DC. (to which must belong Mandon's no. 71 and Spruce's 5789), and *S. isopappa*, Benth., appear to be good species.

HYMENOPAPPUS MEXICANUS. Tomento flocco-canescens, 1–2-pedalis e caudice perenni; foliis aut integerrimis aut pinnatipartitis, lobis oblongo-lanceolatis vel caulinorum linearibus; capitulis laxe subcorymbosis; involucri bracteis ovatis ovalibusque apice tantum petaloideis; corolla (in stirpibus Mexicanis ut videtur sordide alba, in Neo-Mexicanis lutea) lobis parvis fauce campanulata dimidio brevioribus; acheniis secus angulos pubescentibus, faciebus glabellis seu enerviis; pappo minuto (e paleolis minimis) vel obsoleto. — In the higher mountains near San Luis Potosi, Mexico, Sept. 1876, *Schaffner*, seemingly whitish-flowered. New Mexico, in a mountain ravine, near the Mimbres, *Wright*, 1851, a single specimen, reported in Pl. Wright. ii. 94 as *H. flavescens*, var.? Pinos Altos Mountains, *Greene*, July, 1880, and Mogollon Mountains, *Rusby* (no. 179), Sept. 1881. The corollas in Wright's specimens seem to be whitish, but are too old; in Greene's and Rusby's they are clearly yellow. The species is extremely well marked.*

* In all the other species the two or three nerves on the faces of the akenes are conspicuous; at maturity not rarely as prominent as the five angles. In *H. Mexicanus* they are faintly indicated.

H. FILIFOLIUS, Hook., seems to be the only other truly perennial species, and to include *H. luteus*, Nutt.; for flowers appear to vary from dull white to yellow. The teeth of the corolla are much shorter than the throat; the pappus neither very short nor minute, as originally described, though it may be hidden by the long villosity of the akene.

H. TENUIFOLIUS, Pursh, and H. FLAVESCENS, Gray, are biennials, leafy-stemmed and cymosely polycephalous, with conspicuous pappus, and lobes of the corolla more or less shorter than the throat.

H. ARTEMISIÆFOLIUS, DC., with corolla-lobes fully as long as the throat, villous-pubescent akenes, and a rather conspicuous pappus, belongs rather with

H. SCABIOSÆUS, L'Her., and H. CORYMBOSUS, Torr. & Gray; biennials, with larger limb to the corolla, more white-scarious petaloid and lax involucral bracts, and minutely pubescent akenes, with very short and sometimes obsolete pappus.

CHÆNACTIS FREMONTI. Glabrata vel glabra, pedalis; foliis angusto-linearibus aut integerrimis aut lobis 3–5 instructis; capitulis paucis ultra-semipollicaribus; involucri bracteis crassiusculis acutiusculis, costa prominula; corollis albido-carneis, marginalibus limbo eximie ampliato nunc in ligulam veram 5-lobam expanso discum superante; pappi paleis 4 lineari-lanceolatis corollam subæquantibus costa basilari mox evanida instructis. — Desert of the Mohave and Lower Colorado, *Fremont* (imperfect specimen), *Newberry*, *Parish*, *Lemmon*. A very distinct species, with the aspect rather of *C. Xantiana*, but in character nearer *C. stevioides*, with which it has been somewhat confounded. It is the most radiatiform of all the species, the palmato-ampliate limb of the marginal corollas not rarely developed into a short and broad ligule, with five equal and parallel lobes.

CHÆNACTIS NEVII. This name is given to a yellow-flowered species, imperfectly known by a single specimen collected in Idaho by *Rev. R. D. Nevius*, resembling *C. heterocarpha*, but with obsolete pappus.

CHÆNACTIS THYSANOCARPHA. (§ ACARPHÆA, character amplif. Pappus aut nullus, aut deciduous. Achenia subclavata, complanata, nigricantia. Annuæ, involucro viscido, corollis albidis, marginalibus haud ampliatis.) Humilis, gracilis, viscida-puberula, usque ad capitulum parce foliosa; foliis linearibus angustis integerrimis; involucri 7–10-flori bracteis lineari-oblongis; acheniis clavato-obovatis; pappo corolla dimidio breviore deciduo, e paleis 8–9 tenuibus spathulatis eroso-fimbriatis. — Southern part of the Sierra Nevada, California, probably in Kern Co., at 9,800 feet, *Rothrock*, no. 345.

POLYPTERIS, Nutt. Nuttall's genus, founded on *P. integrifolia*, in our opinion, ought not to have been merged in *Palafoxia*, Lag. It is distinguished by the scarious-membranaceous or petaloid-colored tips of the involucral bracts (in the manner of *Florestina*), and by the division of the limb of the corolla almost down to the filiform tube; moreover the style-branches are not so much like those of *Eupatoriaceæ*. Our species fall under three sections. The first, and nearest to *Florestina*, has middle-sized or small and homogamous heads; involucral bracts herbaceous up to the short sphacelate-colored tips; corolla-limb parted down to the slender tube; akenes oblong-pyramidal; and root annual. Here, *P. callosa* (*Stevia callosa*, Nutt., *Palafoxia callosa*, Torr. & Gray), *P. Texana* (*Palafoxia*, DC., &c.), and the Mexican *P. Lindenii*. The second section, with heterogamous and palmately radiate heads, slender akenes, and an annual root, contains

P. Hookeriana, the *Palafoxia Hookeriana*, Torr. & Gray, Fl., and of Hook. Bot. Mag. t. 5549. The third section, for the original species, *P. integrifolia*, Nutt., has a large homogamous head, a short-campanulate throat between the long lobes and the tube of the corolla, slender akenes, a more imbricated and largely whitish-scarious involucre, and a perennial root.*

ACTINELLA (PLATEILEMA) PALMERI. Depressa, subcæspitosa e caudice multicipiti perenni; foliis confertis pinnatifidis cum caulibus brevibus glabris, lobis subovatis; pedunculis gracilibus subscapiformibus monocephalis; involucri bracteis subovatis ciliatis ligulisque 6–8; acheniis secus nervos 4–5 hirsutis, maturis glabratis. — Peculiar in the genus by the following sectional characters: Involucrum oligophyllum, fere herbaceum, subbiseriale, phyllis ima basi subcoalitis. Receptaculum convexum. Pappi paleæ 4–5, chartaceo-scariosæ, quadratæ, enerviæ, ima basi crassiores, apice truncato laciniatæ nunc fissiles, corollis disci dimidio breviores. Folia impunctata et globulis resinosis destituta, querciformia. — Near Saltillo, State of Coahuila, Mexico, April, 1880, no. 554, coll. *Palmer*. †

ACTINELLA INSIGNIS. *A. chrysanthemoidei* sat similis; radice bienni crasso; caule robusto bipedali ramoso polycephalo; foliis 2–3-pinnatipartitis impunctatis, lobis angusto-linearibus, petiolis magis complanato-dilatatis; pedunculis fistulosis; involucri bracteis linearibus laxioribus; receptaculo convexo; pappi paleis 5 lato-ovatis muticis diametrum achenii haud superantibus. — Coahuila, Mexico, at Lerios, in the mountains east ot Saltillo, at 10,000 feet, July, 1880, no. 632,

* PALAFOXIA FEAYI, Gray, Proc. Am. Acad. xii. 59, is certainly a connecting species, the corolla-lobes being fully half the length of the cylindraceous throat, and the tips of the involucral bracts obscurely sphacelate.

P. linearis, Lag., includes *P. leucophylla*, Gray, Proc. Am. Acad. viii. 291, as a shrubby form, with reduced pappus. In cultivation it produced elongated and excurrently costate pappus-paleæ; and the original species is described as shrubby.

P. latifolia, DC., of Southern Mexico, is apparently unknown to recent botanists, but, having "opposite cordate leaves," it can hardly be of this genus.

† ACTINELLA, Pers., Nutt., name changed, as was at the time thought necessary, from *Actinea*, Juss. *Hymenoxys*, Cass., DC. *Actinella, Hymenoxys*, and a part of *Cephalophora*, Benth. & Hook. I have insisted upon the maintenance and full development of this genus in Plantæ Fendlerianæ, Plantæ Wrightianæ, and later in Proc. Am. Acad. xiii. 373. It has now a good number of species, which fall into three natural sections, the first of which is new: —

§ 1. PLATEILEMA. Involucrum oligo- et platyphyllum: receptaculum convexum: pappi paleæ (4–5) quadratæ, truncato-laciniatæ, fissiles.

A. PALMERI, vide supra. Northern Mexico.

Palmer. Thoroughly distinct from the *Actinea chrysanthemoides*, HBK.; the heads and rays as large as in Kunth's figure of that species, larger than in any specimens of it we possess.

HELENIUM THURBERI. *H. ooclinio* affinis, pariter annuum; paleis pappi breviusculis ovatis obtusis muticis; foliis lineari-lanceolatis inte-

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§ 2. EUACTINELLA. Involucrum polyphyllum, simplex, nempe, e bracteis gradatim 2–3-seriatis subæqualibus discretis herbaceis vel submembranaceis: receptaculum sæpius conicum vel hemisphæricum: pappi paleæ sursum sæpius angustatæ vel aristatæ.

* Suffruticosa, caulescens. Am. Merid.

A. HETEROPHYLLA, Juss., sub *Actinea*, Pers. *Cephalophora heterophylla* & *C. radiata* (?), Less. Certainly belongs here rather than to *Cephalophora*. Our specimens are incomplete.

* * Annua, caulescens, integrifolia; receptaculo conico. Am. Bor.

A. LINEARIFOLIA, Torr. & Gray, Fl. ii. 383, ubi syn.

* * * Perennes, Am. Bor., caudice multicipiti, raro simplici.

+ Scaposæ, monocephalæ, plerumque integrifoliæ.

A. SCAPOSA, Nutt., var. LINEARIS, Nutt.

A. ACAULIS, Nutt. — Var. GLABRA. *A. glabra* & *A. Torreyana*, Nutt.

A. DEPRESSA, Torr. & Gray, Pl. Fendl. 100, cum var. PYGMÆA.

+ + Caulescentes, mono–oligocephalæ, integrifoliæ.

A. ARGENTEA, Gray, Pl. Fendl. 100.

A. LEPTOCLADA, Gray, Pacif. E. Exp. iv. 107.

+ + + Caulescentes, humiles, mono–oligocephalæ, sæpius megacephalæ, foliis plerisque divisis.

A. BRANDEGEI, T. C. Porter; Gray, Proc. Am. Acad. xiii. 373.

A. GRANDIFLORA, Torr. & Gray, in Bost. Jour. Nat. Hist. Soc. v. 110.

* * * * Biennes vel annuæ, Mexicanæ, pleio–megacephalæ; caulibus robustis foliosis; foliis omnibus 1–3-pinnatipartitis. — *Hymenoxys*, Benth. & Hook. Gen. l. c.

A. INSIGNIS. Vide supra.

A. CHRYSANTHEMOIDES, HBK. Nov. Gen. & Spec. iv. 298, t. 411, sub *Actinea*. The developed receptacle in all our specimens is high and narrowly conical. The preceding species has probably been confounded with this; but the very different pappus should at once distinguish it.

§ 3. HYMENOXYS. Involucrum pl. m. duplex, e bracteis coriaceis erectis, extimis sæpissime aut basi aut altius cupulato-connatis: receptaculum conicum. Herbæ caulescentes, annuæ, biennes, vel raro perennes. — *Hymenoxys*, DC. excl. sp. ult.

* Capitulum homogamum; involucro utroque 7–8-phyllo, bracteis latis obtusis. — *Hymenoxys*, Cass. Amer. Merid.

A. ANTHEMOIDES, Gray, Pl. Wright. i. 122, &c. *Hymenoxys anthemoides*, Cass. *H. Hænkeana*, DC. Prodr. ?

gerrimis imisve latioribus raro laciniatis; capitulis multo minoribus globoso-ovatis fuscis; receptaculo lato-ovato; ligulis nullis.—S. Arizona, *Coulter* (359, distributed as of Californian collection), *Thurber* (346, wrongly referred to *H. puberulum* in Bot. Mex. Bound.), *Pringle*

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* * Capitulum heterogamum radiatum. Am. Bor. et Mex.

+ Ramosæ, pleiocephalæ; foliis (sp. ultima excepta) plerisque 1–3-pinnati- vel ternati-partitis.

++ Pappi paleæ majusculæ in acumen saltem aristiforme productæ.

A. ODORATA, Gray, Pl. Fendl. 101. E radice annua diffusa; foliorum segmentis filiformibus mollibus; capitulis parvulis sparsis; bracteis involucri externi 7–8 basi tantum coalitis. — *Cephalophora anthemoides*, Less. ex DC. *Hymenoxys odorata*, DC. Prodr. v. 661; Deless. Ic. iv. 42.

A. BIENNIS, Gray, Proc. Am. Acad. xiii. 373. E radice bienni erecta, 1–2-pedalis; foliorum segmentis linearibus rigidulis; capitulis subcymosis majusculis hemisphæricis; involucri laxioris bracteis externis 12–14 vix carinatis; ligulis totidem angusto-cuneatis. — *A. Richardsonii*, var. *canescens*, Eaton, Bot. King, 175; Gray, Bot. Calif. i. 394, forma nana cinerea.

A. RICHARDSONII, Nutt. E caudice multicipiti perennis, spithamæa ad pedalem, fastigiatim ramosa; foliis rigidulis 1–2-ternatopartitis, segmentis filiformi-linearibus, petiolis radicalibus in axillis lanosis; capitulis parvulis; involucro externo 6–9-angulato e bracteis crasso-carinatis infra medium cupulato-connatis; ligulis cuneatis. — *Picradenia Richardsonii*, Hook. Fl. i. 317, t. 108.

++ ++ Pappi paleæ breviores muticæ: caules erecti 1–2-pedales e radice perenni, vel bienni.

A. VASEYI, Gray, Proc. Am. Acad. xvii. 219. Subglabra; capitulis majusculis fastigiato-cymnosis; involucro campanulato, externo e bracteis 7–9 carinatis longe in cupulam 7–9-dentatam interius æquantem connatis; pappi paleis oblongis tenuibus obtusis vel obtusiusculis corolla disci dimidio brevioribus; segmentis foliorum linearibus saltem trifidis. — Still known only by the few specimens collected in New Mexico by *George R. Vasey*.

A. COOPERI, Gray, Proc. Am. Acad. vii. 394. Puberula, 2–3-pedalis e caudice ut videtur perenni, superne paniculato-ramosa; capitulis sparsis; involucro fere hemisphærico, externo e bracteis 6–10 basi connatis; pappi paleis latis obtusissimis apice erosis hyalinis corolla disci plus dimidio brevioribus; foliis inferioribus biternatim quinatimve superioribus tantum 3–5-partitis in segmenta fere filiformia. — S. E. California, *Cooper*, an incomplete specimen, in which the pappus seemed to be of firm texture. S. W. Arizona, on high slopes, Tanner's Cañon, *Lemmon*, complete specimens: pappus thin and hyaline.

A. RUSBYI. E radice lignescente (ut videtur bienni?) ultrapedalis, stricta, glabra, apice fastigiatim ramosa, polycephala; foliis rigidulis linearibus, radicalibus elongatis angustis cum caulinis inferioribus aliis integerrimis aliis tripartitis, superioribus omnino integerrimis; capitulis parvis (lin. 3 altis) confertis; involucro externo e bracteis 7–8 subulato-lanceolatis ima basi tantum connatis; ligulis totidem lin. 2–3 longis quadratis; pappi paleis 5 quadratis seu latissime cuneatis truncatis rigidulis prorsus enerviis tubum proprium corollæ

(137, was referred to *H. ooclinium*): a well-marked and apparently always rayless species.

Gaillardia Mexicana. Primo intuitu *G. lanceolatæ* sat similis, sed microcephala, humilior; radice perenni; involucro basi calloso; corollis disci dentibus brevi-oblongis obtusis; villis achenii parcioribus; fimbrillis receptaculi perplurimis setiformibus achenio cum pappo suo adæquantibus.— Northern Mexico, *Palmer*, in the Sierra Madre, south of Saltillo, no. 725; also in a dwarf and subcaulescent form at Lerios, in the mountains east of Saltillo, no. 726. Collected in the same region, but without the root, by Gregg, no. 113, 160, also in the mountains near San Luis Potosi, by Schaffner, Sept., 1876, no. 259. Moreover it is no. 374 of coll. *C. Wright*, in 1849, on the Rio Frio, in S. W. Texas, which was wrongly referred to *G. pulchella*.

Gaillardia comosa. *G. simplici*, Scheele, affinis (§ *Guntheria*, *Agassizia*, Gray & Engelm.), humilis; foliis omnibus radicalibus 1–2-pinnatipartitis vel paucis laciniatis; scapo spithamæo; involucro triseriali parvulo; ligulis breviusculis fertilibus; acheniis longissime denseque villosissimis, villis pappi paleas oblongo-lanceolatas costa breviter excurrente aristulatas corollam disci subæquantes fere tegentibus; receptaculi fimbrillis brevissimis mollibus.—Northern Mexico, near Saltillo, April, 1880, no. 721, *Palmer*. The long villi of the achenium are found to be inserted over its whole surface in *G. simplex* and *G. pinnatifida* no less than in the present species, in which they so abound as to form a dense pellet.

Sartwellia Mexicana. Foliis angustissime linearibus; pappo e paleis 4–5 angusto-oblongis apice truncato fimbriolatis cum aristis alternantibus gracillimis longioribus, omnibus ima basi tantum connatis. — Northern Mexico, near Monclova and San Lorenzo de Laguna, south of Parras, *Palmer*, 683, 687. A very interesting accession to a genus which was supposed to be monotypic. The pappus is as if the cupule of *S. Flaveriæ* were resolved into four or five paleæ, with

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disci haud superantibus.—Grassy slopes of the Mogollon Mountains, New Mexico, *H. H. Rusby*, Sept., 1881.

+ + Simplex vel subsimplex e caudice perenni, monocephala; foliis angustissime linearibus rigidulis fere semper integerrimis impunctatis; involucro utroque 12–14-phyllo consimili, vel interno e bracteis magis attenuato-acuminatis, iis externi ima basi parum connatis; pappi paleis circa 10 subulato lanceolatis sensim aristato-acuminatis corollam disci fere æquantibus.

A. Bigelovii, Gray, Pl. Wright. ii. 97, & Bot. Mex. Bound. 99.—New Mexico, first coll. by *Dr. Bigelow.* Connects *Hymenoxys* with *Euactinella*, and with the section *Dugaldea* of *Helenium*.

the interposition of as many delicate and scabrous awns, the latter of nearly the length of the cylindrical akene.

FLAVERIA CHLORÆFOLIA, Gray, Pl. Fendl. 88. Among the abundant specimens of this well-marked species in Palmer's Mexican collection (682, 2083), one was noticed in which most of the flowers had a pappus of four oblong and entire paleæ!

POROPHYLLUM FILIFOLIUM. Caulibus e radice perenni gracillimis simpliciusculis rigidulis monocephalis; foliis omnibus alternis filiformibus plerisque pollicaribus, summis parvis; involucro brevi-campanulato 8–9-phyllo, bracteis lato-oblongis obtusissimis crassiusculis flores (multos) purpurascentes æquantibus; tubo corollæ fauce subinfundibuliformi cum dentibus ovatis 2–3-plo breviori; acheniis gracilibus apice haud angustatis pappo subparco barbellulato parum longioribus.— Northern Mexico, in the Sierra Madre, south of Saltillo, *Palmer*, 688, mixed in the distribution with a little *Thelesperma subsimplicifolium.* Belongs to the section which contains *P. scoparium* and *P. amplexicaule;* but with more dilated throat to the corolla. The last-named two species are remarkable for the slender corolla, of which the greater part is a narrow tubular throat, raised on a decidedly shorter proper tube, and surmounted by very short and blunt teeth. In this they agree with *Chrysactinia.*

POROPHYLLUM ERVENDBERGII. *P. ruderali* var. *elliptico* sat similis, multo minus; foliis omnibus oppositis oblongis; capitulis gracillimis 10–15-floris; involucro semipollicari.—*P. ellipticum*, var. Gray, Proc. Am. Acad. v. 184.—Wartenberg, Mexico, *Ervendberg*, no. 75.*

DYSODIA and the genera nearly allied to it are of difficult limitation. A renewed study of nearly all the species concerned obliges me to modify the view adopted by Bentham in the Genera Plantarum,

* A few Mexican species may be noted as follows:—

POROPHYLLUM VIRIDIFLORUM, DC., to which Hartweg's no. 147 has rightly been referred, comprises *P. Lindenii*, Schultz Bip., if Hemsley has correctly identified Seemann's with Hartweg's plant.

POROPHYLLUM SEEMANNI, Schultz Bip. Bot. Herald, 308. Seemingly a variety of this, with narrower and mostly attenuate-acute or acuminate leaves (the base tapering into a petiole) is a plant from "Mexico, *Tate*," long ago received from duplicates of Herb. Hooker. By the elongated corolla tube it belongs to the same group with the broad-leaved petiolate species.

POROPHYLLUM OBTUSIFOLIUM, DC., we know only from the specimens of Mendez. It appears to be truly perennial, has the involucre either bright violet-purple or sometimes greenish, the leaves mainly tapering somewhat into a petiole; the limb of the corolla deeply 5-parted into oblong-lanceolate lobes, and

and to recall the reference I had formerly made, and he had accepted, of *Lebetina* to *Adenophyllum*. This was the result of giving prominence to the double pappus of unlike form. But this character breaks down in respect to *Lebetina cancellata* and *Dysodia porophylla*, DC., which are likely to prove mere forms of one species, and would carry some genuine *Hymenathera* to *Adenophyllum*. A better limitation of the genera is as follows: —

ADENOPHYLLUM, Pers. (*Willdenovia*, Cav.), with involucre and calyculate bractlets of *Eudysodia*, habit between that and *Tagetes*, disk-corollas at least sometimes unequally cleft into long and narrow linear lobes; and a double pappus, each of five paleæ; the outer short and truncate; the inner elongated-lanceolate, entire or with a pair of subulate teeth at apex where the strong costa is excurrent into a short awn. The filiform style-branches are hispidulous above, at summit abruptly produced into a hispidulous setaceous appendage. The single species, *A. coccineum*, Pers.

DYSODIA, Cav., and chiefly of Lagasca, the distinguishing character of which is the multisetose polyadelphous pappus, i. e. the 10 to 20 paleæ are resolved each into numerous (at least 9 or 10) long capillary bristles. In one species only, *D. cancellata*, is there a different outer series, the short paleæ of which are usually entire, yet occasionally setiferous. The involucre is not so diagnostic; for, although mostly calyculate with accessory bractlets, and gamophyllous only at base, or not at all, in *D. serratifolia* (which can in no wise be referred to *Hymenatherum*) it is even that of *Tagetes*.

HYMENATHERUM, Cass, connected with the preceding by *Aciphyl-*

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about the length of the narrow throat (i. e. of the portion of tube above the insertion of the stamens), which again is only equalled by the proper tube.

POROPHYLLUM GRACILE, Benth. Bot. Sulph. 29. To this probably belongs no. 449 of Coulter's Mexican collection, a depauperate form.

POROPHYLLUM LINARIA, DC. (*Cacalia Linaria*, Cav. Ic. iii. 257). To this we should refer Coulter's no. 448, Parry & Palmer's 502, Schaffner's 268, and with little doubt Hartweg's 146. It is distinguished from the next by its perennial root, thickish more sessile leaves, &c.

POROPHYLLUM COLORATUM, DC. The annual species with thinnish narrow leaves, and violet-purple involucres, with little doubt including *P. tagetioides*, DC., *Kleinia tagetioides* and *K. colorata*, HBK., well figured under the latter name in Mart. Amœn. Monac. 28, t. 15. It comes from Schaffner, Bilimek, &c., and is Bourgeau's 584, 3091.

POROPHYLLUM SUFFRUTICOSUM is a name which should be adopted for a South Brazilian species which seems to have been taken for Mexican, if — as I suppose — it is *Kleinia suffruticosa*, Willd., and also of Lodd. Bot. Cab., t. 1561, *P. linifolium* (mainly), and *P. decumbens*, DC.

læa, — a genus which I extended in Pl. Fendlerianæ, and again in Pl. Wrightianæ, and to which must now be added *Adenophyllum Wrightii* of the latter work, and even *Thymophylla*, Lag., — is distinguished from *Dysodia* by its pappus of at most 1–5-aristate paleæ, or else some or even all of them muticous; and the simple campanulate involucre is wholly gamophyllous. In this genus we find all gradations between a simple and a double pappus. The branches of the style are truncate, and either with or without an apiculation or an obscure cone.

The species of these genera may be arranged and characterized as in the foot-note.*

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*DYSODIA (*Dyssodia*), Cav.

§ 1. Gymnolæna, DC. Involucrum campanulatum, sæpius modo *Tagetis* alte gamophyllum basi fere nudum: styli rami ex apice truncato-subpenicillato subito tenuiter appendiculati: receptaculum alveolato-dentatum, pubescens: capitula solitaria pedunculata, majuscula: folia præter lobulos stipuliformes indivisa, opposita.

D. sessilifolia, DC. Prodr. v. 641. *Hymenatherum sessilifolium*, Hemsl. Bot. Biol. Centr.-Am. ii. 241, referred to that genus on account of a note in Benth. & Hook. Gen. Pl., but it is like *Hymenatherum* only in the gamophyllous involucre. Style-appendages slender, nearly setiform.

D. integrifolia. Gracilis, glabra; foliis angusto-lanceolatis adpresso-serrulatis basi attenuatis subpetiolatis basi utrinque lobulo subulato-setaceo instructis (inferioribus ignotis); involucro (semipollicari) bracteolis paucis parvis lineari-subulatis calyculato, bracteis propriis angusto-lanceolatis infra medium tantum coalitis; ligulis aureis; styli fl. herm. ramis apiculo tenui brevi terminatis. — District of Chiapas, Mexico, along streams in the mountains, no. 784, *Ghiesbreght*. Leaves not half the size of those of *D. serratifolia*, which is no. 519 of Ghiesbreght, and which is said to have "fleurs rouge tres vif." In this species they are obviously yellow.

§ 2. Eudysodia. Involucrum campanulatum vel hemisphæricum basi calyculato-fulcratum, bracteis inferne tantum coalitis vel liberis: styli rami aut præcedentis (*D. porophylla* & *cancellata*), aut plerumque sensim in appendicem gracilem tenui-subulatam producti: corollæ dentes sæpius angusti: receptaculum pl. m. fimbrilliferum: capitula majuscula, pedunculata, ramos apice nudos terminantia: herbæ perennes nunc suffruticosæ, oppositifoliæ et alternifoliæ. — *Dysodia* § *Eudysodia*, *Bœbera* pro parte, *Bœberoides*, et gen. *Clomenocoma* (Cass.), DC.

* Receptaculum eximie setoso-fimbrilliferum: achenia pubescentia: capitula speciosa: folia omnia opposita. — *Clomenocoma*, Cass. *Comaclinium*, Scheidw. & Planchon. *Clappia* pro parte, Benth.

+ Bracteæ accessoriæ involucri ovatæ.

D. grandiflora, DC. Prodr. v. 640. "Folia ovali-lanceolata, argute serrata, acuminata; involucro bracteis ovatis subdentatis acuminatis cincto"; pappo

Tagetes, Tourn., is so natural that no question of its limitation has been raised. Its involucre varies from oblong-campanulate to tubular or to ovate and ventricose. The akenes are angulate or compressed,

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fere semipollicari, setis pauciusculis rigidulis. — This is not identical with *Clomenocoma montana* of Bentham, as he (in Addenda to Pl. Hartw. 351) has suggested.

D. squamosa. Folia trifoliolata, foliolis ovatis petiolulatis serratis: bracteæ accessoriæ *scariosæ*, apiculato-acuminatæ vel muticæ, propriis vix breviores: pappi paleæ setis numerosis mollibus. — *Dysodia appendiculata*, Schultz Bip. in Bot. Herald, non Lag. — Northern part of Mexico, *Gregg*, no. 1061. *Seemann*, 1991.

+ + Bracteæ accessoriæ angustæ.

D. appendiculata, Lag. Nov. Gen. & Spec. 29. Folia pinnata paucijuga: involucri bracteæ accessoriæ numerosæ, subulatæ vel setaceo-attenuatæ. — *Aster Americanus*, etc. Houst. Rel. t. 18. *A. aurantius*, L. *Clomenocoma aurantia*, Cass. Dict. ix. 416, lix. 66; DC. l. c. *Clappia aurantiaca*, Benth. Ic. Pl. xii. 3, t. 1104; unless, indeed, the involucre is quite correctly delineated in the figure as to the pluriserially imbricated bracts. If so, it is a peculiar but otherwise similar species.

D. montana. Folia ovata seu ovato-lanceolata, indivisa et serrata, summisve inciso-pinnatifida: involucri bracteæ accessoriæ paucæ, lineares. — *Clomenocoma montana*, Benth. Pl. Hartw. 86; Hook. Bot. Mag. t. 5310, excl. syn. DC. Prodr. *Comaclinium aurantiacum*, Scheidw. & Planchon, Fl. Serres, t. 756. *Dysodia grandiflora*, Hemsl. Bot. Biol. Centr.-Am. ii. 219, non DC. — Guatemala and Nicaragua.

* * Receptaculum brevissime fimbrilliferum, pubescens, vel subalveolatum: bracteæ accessoriæ tenuiter subulatæ vel setaceæ: achenia glaberrima vel minute puberula, pappo breviora: plantæ plerumque glaberrimæ, ramosæ, caulibus basi sublignosis vel frutescentibus.

++ Folia omnia opposita, trifoliolata, petiolis petiolulisque gracilibus.

D. speciosa, Gray, Proc. Am. Acad. v. 168. Lower California, *Xantus*.

++ ++ Folia omnia vel plera alterna, laciniato-pinnatipartita, raro indivisa.

= Styli rami ex apice obtuso subpenicillato subito tenuiter appendiculati: foliorum lobi et involucri bracteæ accessoriæ seta tenuissima protracta terminati. Spec. duæ, Mexicanæ, pappo tantum diversæ, in priore (*Lebetina*, Cass.) anomalo.

D. cancellata. Pappus duplex, exterior e paleis 10 brevibus oblongis vel obovatis coriaceis integerrimis apice quandoque denticulatis vel pauciseluliferis. — *D. Porophyllum*, Willd. Enum. 900, non Cav. *Lebetina cancellata*, Cass., DC. *Bœbera Porophyllum*, Less. *Adenophyllum Porophyllum*, Hemsl. Biol. Centr.-Am., mainly. — This appears to be usually more robust than the following, more conspicuously radiate, and the paleaceous portion of the inner or ordinary pappus is more conspicuous and firmer than in the following. But the two probably had a not remote common ancestry.

D. porophylla, Cav. Anal. Cienc. vi. 334; DC. Prodr. v. 639. *Pteronia Porophyllum*, Cav. Ic. iii. 13, t. 225, discoid form. *Bœbera Porophyllum*, HBK. *Ade-*

hardly at all striate; the pappus is composed of very few and usually coriaceous paleæ; some of which are apt to be aristiform, but none setiferous.

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nophyllum capillaceum, DC. l. c. 638, unless that should be the preceding. *A. Porophyllum*, Hemsl. l. c., in part.

= = Styli rami in appendicem elongato-subulatam hirsutam sensim producti: folia vix setigera.

D. POROPHYLLOIDES, Gray, Pl. Thurb. 322, & Bot. Calif. i. 397. Caules basi lignosi: folia 3–5-partita, segmentis angustis dentibusque cum bracteis involucri externi subulato-acutatis nec setiferis. — Southeastern California and Arizona.

D. COOPERI, Gray, Proc. Am. Acad. ix. 201, & Bot. Calif. l. c. Caules basi minus vel vix lignosi: folia omnia alterna, brevia, ovata et sublanceolata, arcte sessilia, subspinuloso-dentata, nonnulla basi utrinque lobo parvo stipuliformi instructa: capitulum pollicare, involucro 20–30-phyllo cum bracteis accessoriis parvis. — Southeastern California.

§ 3. BŒBERA, DC. excl. sp. Capitula minora; involucro fere præcedentis; bracteis accessoriis subfoliaceis veras subæquantibus: styli rami fl. herm. cono brevi nunc obtuso superati: corollæ dentes breves ovati: receptaculum puberulum: achenia puberula: herbæ sæpius pubescentes, foliis oppositis pinnatipartitis, segmentis angustis plerumque dentatis vel incisis.

* Herbæ perennes (an semper?), capitulis mediocribus ramos terminantibus longius pedunculatis, ligulis exsertis conspicuis.

D. TAGETIFLORA, Lag. l. c.; Gray, Pl. Wright. i. 114. Caules elongati: pedunculi superne incrassati: involucrum glabellum, bracteis accessoriis lanceolato-subulatis acutis. — *Bœbera fastigiata*, HBK. Nov. Gen. & Spec. iv. 148. *B. tagetiflora*, Spreng. Syst. DeCandolle confounded this with his *D. appendiculata*, at least in his herbarium, and referred the synonymous names to his *D. fastigiata*, which otherwise is *D. chrysanthemoides*. And Hemsley omits the species, taking only partial note of the remarks in Pl. Wrightianæ. To this belongs no. 2560 of Bourgeau.

D. PUBESCENS, Lag. l. c. Humilior, mox diffusa: pedunculi sursum vix incrassati: involucrum sæpius pubescens, bracteis accessoriis oblongo- seu lineari-spathulatis obtusis. — *Aster pinnatus*, Cav. Ic. iii. 6, t. 212. *Dysodia integerrima*, Lag. l. c., a form with narrow subentire leaf-segments. *Bœbera incana*, Lindl. Bot. Reg. t. 1602. *Dysodia incana* & *Clomenocoma pinnata*, DC.

* * Herba annua, ramosissima, usque ad capitula parvula foliosissima; foliis majus divisis; ligulis parvis inconspicuis. — *Bœbera*, Willd.

D. CHRYSANTHEMOIDES, Lag. l. c., cum syn. DC. Prodromi. *D. fastigiata*, DC. l. c., excl. syn. — Mississippi Valley to Mexico.

§ 4. BŒBERASTRUM. Involucrum laxius, depresso-hemisphæricum, simplicissimum, e bracteis 8–9 obovatis membranaceis margine subscariosis ima basi subincrassatis, accessoriis plane nullis: ligulæ conspicuæ rotundatæ: corollæ disci lobis longiusculis: styli rami cono brevi acuto superati: pappi setæ ratione

TAGETES LEMMONI. Fere glaberrima, 2–3-pedalis; caulibus strictis superne subfastigiatim ramosis paniculato-polycephalis; foliis omnibus oppositis; foliolis 5–7 lanceolato- seu elliptico-linearibus æqualiter ser-

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paleæ breviusculæ, lateralibus inferioribus brevissimis: herba annua, humilis, glabra, diffusa, foliis alternis lineari-pinnatipartitis.

D. ANTHEMIDIFOLIA, Benth. Bot. Sulph. 29. — Lower California, *Hinds*, *Dr. Streets*.

HYMENATHERUM, Cass. 1817, 1818. *Hymenatherum* (excl. § 2), *Dysodia* § *Aciphyllæa*, *Gnaphaliopsis*, DC., cum *Thymophylla*, Lag. & *Lowellia*, Gray.

§ 1. ACIPHYLLÆA, DC. (sub *Dysodia*), Gray, Pl. Wright. i. 115. Paleæ pappi simplicis 18–20, angustæ, superne in setas capillares 3–5 dissolutæ: suffrutex foliis integerrimis aceroso-filiformibus oppositis, capitulis subsessilibus.

H. ACEROSUM, Gray, l. c. *Dysodia ? acerosa*, DC. *Aciphyllæa acerosa*, Gray, Pl. Fendl. 88.

§ 2. DYSODIOPSIS, Gray, Pl. Wright. l. c. excl. spec. Paleæ pappi simplicis 10, rigidæ, achenio breviusculo haud longiores, lanceolatæ, corolla disci breviores, aliæ apice subulato-acuminatæ, aliæ apice fissæ trisubulatæ: herba foliis alternis pinnatifido-dentatis, capitulis folioloso-calyculatis.

H. TAGETOIDES, Gray, l. c. *Dysodia tagetoides*, Torr. & Gray, Fl. ii. 361. Texas.

§ 3. EUHYMENATHERUM. Pappi paleæ 10–20, aut omnes aut interiores 1–3-aristatæ, aristis corolla disci vix brevioribus: capitula sæpissime pedunculata, basi parum bracteolata vel nuda.

* Ligulæ paucæ, brevissimæ, inconspicuæ: pappus rigidus, duplex, utroque 10-paleaceo, paleis exterioris truncato-obtusis, interioris triaristatis: herba annua, erecta, glabra; capitulis brevi-pedunculatis bracteolis paucis setaceis subtensis.

H. NEO-MEXICANUM. *Adenophyllum Wrightii*, Gray, Pl. Wright. ii. 92. — New Mexico, found only by Wright. Certainly of this genus.

* * Ligulæ exsertæ, conspicuæ: pappus minus rigidulus, aristis capillaribus vel tenui-setiformibus.

+– Herbæ annuæ, glaberrimæ (nunc pedunculis minutissime glanduloso-puberulis), humiles, diffuso-ramosissimæ, floribundæ; pedunculis breviusculis; foliis mollibus pinnatipartitis in segmenta sublineari-filiformia obtusa prorsus mutica, superioribus alternis.

H. POLYCHÆTUM, Gray, Pl. Wright, i. 116. Pappi paleæ 18–20, angustissimæ, inæquales, plerumque uniaristatæ et bi- (raro 4-) aristulatæ, exteriores minores magis attenuatæ uniaristulatæ. — Texas and New Mexico.

H. DIFFUSUM, Gray, l. c. Pappi paleæ 10 brevi-lanceolatæ, in aristam 3–4-plo longiorem inter setulas vel dentes breviter aristulatos 2 productæ, et 2–5 parvæ simplicissimæ subuliformes in serie externa imperfecta. — Mexico, *Tate*, in herb. Hook., only specimen yet known to me.

H. TENUIFOLIUM, Cass. Dict. xxii. 313. Pappi paleæ 10, breves, oblongæ, 2–3-aristatæ, aristis lateralibus centrali dimidio brevioribus tenuioribus, raro setulis 2 adjectis, additæ 2–3 minimæ setiformes inconspicuæ. — I had con-

ratis (lin. 2–4 latis, majoribus sesqui-bipollicaribus); pedunculis breviusculis gracilibus subulato-bracteolatis; involucro oblongo-campanulato subturbinato glandulis ovalibus oblongisve maculato; ligulis 6–8 semi-

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nected this with *H. tenuilobum*, DC.; but having two or three akenes and pappus of the original in herb. Jussieu, I can nearly identify it with a plant collected by Schaffner in the "Valley of Mexico, no. 81," given to me by Schultz Bip., under the name of *H. diffusum*. The two, and also the next, appear to be quite alike except in the pappus. Cassini's plant probably was not Chilian.

H. Næi, DC. Prodr. v. 642. Pappi paleæ 10, oblongæ vel obovatæ apice bifidæ, lobis muticis, aut omnes aut 6–7 aut 5 interiores longe tenuiter aristatæ. — Gray, Pl. Wright. l. c. Also *H. bæberoides*, Gray, l. c. This is no. 517, coll. *Parry & Palmer* (referred to *H. diffusum* in Hemsley's Bot. Biol. Centr.-Am.), at least as to my specimen. I seem not to have no. 513.

+ + Herbæ perennes vel subperennes radice gracili, glabræ vel glabellæ; pedunculis sparsis longiusculis, foliis plerisque alternis rigidiusculis mucrone acutissimo vel setuliformi apiculatis: pappi paleæ 10, consimiles, omnes 2–3-aristatæ.

H. Wrightii, Gray, Pl. Fendl. 89. Subpedale, sæpius erectum; foliis integerrimis vel paucilobatis angusto-linearibus vel subfiliformibus; capitulis majusculis. — Texas.

H. tenuilobum, DC. l. c. Diffusum; foliis pinnatipartitis, lobis brevibus subulato-filiformibus; pappo rigidulo, aristis palea vix longioribus. — *H. tenuifolium*, Gray, Pl. Wright, i. 118, non Cass. — Texas and adjacent Mexico.

+ + + Herbæ perennes basi plerumque suffruticulosæ; pedunculis elongatis filiformibus; foliis rigidioribus pinnato-3-7-partitis, segmentis filiformibus seu acerosis setuloso-apiculatis: pappus 10-paleaceus;

++ Paleis omnibus aristatis vel subulato-acuminatis lanceolatis, exterioribus brevioribus sæpius integerrimis, interioribus setuloso-bidentatis: plantæ puberulæ, segmentis foliorum setaceo-acerosis.

H. Belenidium, DC. Prodr. vii. 292. *H. Candolleanum*, Hook. & Arn. Jour. Bot. iii. 320. — The South Chilian species, from Mendoza, *Gillies*. And to this belongs a plant in Hænke's herbarium, at Prague, ticketed "*H. Næi*" by De Candolle.

H. Thurberi. Facie *H. pentachæti*, sed fere herbaceum; pappi paleis parum biseriatis angusto-lanceolatis, minoribus aristato-subulatis. — *H. tenuifolium* var. ? Gray, Pl. Wright. ii. 93. — Borders of W. Texas and Mexico, near El Paso, &c., *Wright* (1408), *Thurber* (746); and a seeming form of the same was collected by *Parry* in 1878.

++ ++ Pappus plane duplex, utroque 5-paleaceo scarioso; paleis exterioris brevioribus spatulatis seu oblongis apice obtusis vel erosis muticis, interioris lanceolatis oblongisve inter dentes 2 subulatos nunc aristulatos uniaristatis: suffruticulosæ, cinereo-pubescentes vel glabellæ, humiles, diffusæ, Texano-Mexicanæ.

= Oppositifoliæ, floribundæ.

H. Hartwegi, Gray, Pl. Wright, i. 117. *H. Berlandieri*, Benth. Pl. Hartw. 18, non DC.

pollicaribus; corolla disci lobis fere imberbibus; pappi paleis brevibus inæqualibus, 1–3 subulatis cæteris 2–3-plo longioribus. — Huachuca Mountains, S. Arizona, *Lemmon*, 1882. A shorter-leaved form, apparently of this species, was scantily collected in the Santa Catalina Mountains, in 1881.†

· = = Subalternifoliæ, capitulis sparsis.

H. PENTACHÆTUM, DC. (Gray, Pl. Wright. l. c.), with *H. Berlandieri*, DC. Prodr. v. 642.

H. TRÉCULII. Laxe diffusum vel decumbens, subherbaceum, fere glabrum: foliis crassiusculis pectinato-pinnatipartitis, lobis brevibus lineari-subulatis, rhachi latiore. — H. n. sp.? no. 13, Gray, Pl. Wright. i. 116. — S. E. Texas, *Trécul*. Too little known.

+ + Herba annuæ, depressæ, floccoso-lanosissima, *Micropi* modo; foliis mollibus plerumque alternis spathulatis integerrimis; capitulis brevi-pedunculatis vel sessilibus; ligulis brevibus ovalibus. — *Gnaphaliopsis*, DC.

H. GNAPHALIOPSIS, Gray, Pl. Fendl. 90 (*gnaphalodes*) & 115, Pl. Wright, l. c. *Gnaphaliopsis micropoides*, DC. Prodr. vii. 258. — Texano-Mexican.

§ 4. THYMOPHYLLA. Pappi paleæ 5–12, truncatæ, muticæ (nunc 3–4 interiores breviter aristatæ vel aristiformes!), subcoriaceæ, quandoque in cupulam connatæ. — *Thymophylla*, Lag. Nov. Gen. & Spec. 25; Gray, Pl. Fendl. 91, & Pl. Wright. i. 119; Benth. & Hook. Gen. (*Thymophyllum*).

* Fruticuli *Hymenatheris* acerosifoliis simillimi, sed albo-tomentosi: ligulæ sæpius nulli. — *Thymophylla*, Gray, l. c.

H. SETIFOLIUM. *Thymophylla setifolia*, Lag. l. c.; Gray, Pl. Wright. l. c. t. 7, fig. 10, 11. — Northern Mexico. On this plant Lagasca's long unknown and imperfectly characterized genus was founded, a little earlier than *Hymenatherum*, which nevertheless it could not now well supersede. It was becoming evident that the separate genus could not stand, when it was discovered that in some of the specimens of no. 516, *Parry & Palmer*, there is an inner series of 3 or 4 aristate or aristiform paleæ, the plants mingled with and otherwise not distinguishable from those with the ordinary pappus of 5 or 6 truncate paleæ.

H. GREGGII. *Thymophylla Greggii*, Gray, l. c. t. 7, forma radiata. Pappus cupuliformis, truncatus. — Texano-Mexican.

* * Annua, glaberrima, pluriradiata, facie *H. tenuifolii*, etc. — *Lowellia*, Gray.

H. AUREUM. *Lowellia aurea*, Gray, Pl. Fendl. 89, Pl. Wright. i. 118. — S. Colorado and W. Texas.

† TAGETES, Tourn. — The following are the principal species: —

§ 1. *Pectidiformes*, DC., integrifoliæ, radiatæ.

T. LUCIDA, Cav. *T. florida*, Sweet, Brit. Fl. Gard. ser. 2, t. 35. *T. Schiedeana*, Less. in Linnæa, ix. 271.

§ 2. *Macrocephalæ*, DC., pinnatifoliæ, capitulis multifloris, ligulis exsertis.

* Laxe ramosæ, radice perenni, foliolis serratis, dentibus vix setigeris.

T. LEMMONI; vide supra.

T. PARRYI, Gray, Proc. Am. Acad. xv. 41. Puberula, laxe ramosa, 1–3-

Pectis. Mr. Bentham remarked, in Gen. Pl. ii. 412, that the sections of *Pectis* proposed in Pl. Wright. i. 83, might probably be recast with advantage. The genus is very natural; and, although two or

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pedalis; ramis monocephalis, capitulo majusculo in pedunculo nudo sæpius elongato apice turbinato fistuloso; foliis oppositis et alternis; foliolis ovalibus oblongisve ligulis 8 latis ultra-semipollicaribus; corollæ lobis intus barbatis, dentibus patentissimis. — Hills southeast of San Luis Potosi, Mexico, *Parry & Palmer*, 504. Now in cultivation; a handsome but late- and sparsely-flowered species.

T. Zypaquirensis, Humb. & Bonpl. of New Granada and Ecuador, to which the above has some affinity, although said by Bonpland to be annual, is probably perennial. A specimen of coll. *André* is ticketed "Frutex dumosus."

T. elliptica, Smith, of Ecuador or Peru, is unknown as to duration, and may also be perennial.

T. pauciloba, DC. A suffruticose Chilian species, with small linear leaflets, very little known.

* * Annuæ, foliolis lanceolatis seu linearibus sæpissime pinnatifido-dentatis, dentibus fol. juniorum plerumque setigeris: pappi paleæ nonnullæ aristiformes, demum ultra involucrum exsertæ.

T. patula, L.; Sims, Bot. Mag. t. 150, etc. *T. erecta*, L.; Lam. Ill. t. 684, etc., grosser form, enlarged by cultivation, the peduncle ventricose-dilated under the thick head. *T. corymbosa*, Sweet, Brit. Fl. Gard. t. 151; Hook. Bot. Mag. t. 3830; the latter a more slender and normal form. *T. remotiflora*, Kunze in Linnæa, xx. 23. To this doubtless no. 3204 of *Bourgeau* is to be referred; while 583 goes rather to the following. The lines between the two are difficult to draw.

T. tenuifolia, Cav. Ic. ii. 54, t. 169; HBK. Nov. Gen. & Spec.; Hook. Bot. Mag. t. 2045, perhaps originally from Mexico, rather than "Peru." *T. peduncularis*, Lag. & Rod. 1802; DC., etc.; smaller forms, with shorter and more laciniate leaflets. *T. lunulata*, Ort.? *T. elongata*, Willd. Spec. iii. 2127? *T. signata*, Bartl. Ind. Sem. Gœtt. 1837, & DC. Prodr. vii. 292; Rev. Hort. 1863, t. 11, a floribund variety of cultivation.

T. subvillosa, Lag., is a still unrecognized Mexican species.

§ 3. *Leptocephalæ*, DC., pinnatifoliæ, annuæ, capitulis plerumque angustis, ligulis paucis inconspicuis raro nullis.

The Mexican species known to us appear to be the following: —

* Foliola vel segmenta serrata vel incisa.

T. fœtidissima, DC. — Well characterized by its numerous oblong-linear and obtuse leaflets, serrate with very many teeth; short-peduncled narrow heads, mostly clustered at the summit of the branches, and the one or two awns of the pappus fully the length of the akene. This, rather than *T. coronopifolia*, Willd., may be *T. clandestina*, Lag.

T. subulata, Llave & Lex., Nov. Veg. Descr. i. 31. *T. multiseta*, DC., and probably *T. oligocephala*, DC. *T. Wislizeni*, Gray, Pl. Fendl. 92. — Known by the 1-2-pinnately divided leaves, with subulate mostly long-setiferous divisions or lobes, long and filiform peduncles, and awns of the pappus very much longer

three genera have been made from it, it seems incapable of division even into well-marked subgenera. The principal available characters are given by the pappus; but this is apt to be reduced, or even to disappear, in some specimens of almost every group. *Pectidopsis* was founded on an awnless state of a not uncommonly 1–2-awned species. *Pectidium*, with the anomalous *Pectis imberbis* (of similar habit, but a perennial), along with the two species of *Heteropectis*, which are annuals with the ordinary *Pectis* habit, may be associated by the character of the two or three corneous awns. In *P. punctata* these are not always completely smooth and naked; an occasional upturned denticulation has been observed. Allowing that in every section the pappus may in the same species be sometimes obsolete or reduced to a crown, the genus may be fairly well disposed of under three sections: —

1. Eupectis. Pappus paucipaleaceus, vel pauci-aristatus aristis setiformibus, nunc ex aristis et paleolis paucis vel definitis constans, plerumque uniserialis.

2. Pectothrix. Pappus (saltem fl. disci) multisetosus, inæqualis, plerumque biserialis, setis interioribus validioribus quandoque aristiformibus inferne sensim latioribus nec vero paleaceis.

(even the paleæ longer) than the akenes. No. 688 of Fendler's Venezuelan collection is a very similar plant, except for the shorter peduncles, and may be probably referred to the same species. The paleæ and awns of the pappus are not rarely connate into a tube.

* * Segmenta foliorum angustissima, integerrima, vel hinc inde lobulata.

T. coronopifolia, Willd. Enum. Suppl. 60 (sine char.); Jacq. f. Eclog. i. 118, t. 80. *T. angustifolia*, HBK. Nov. Gen. & Spec. iv. 194. There are cultivated specimens in the Berlin herbarium, and the original of Humboldt at the Paris Museum. In both, as I learn from comparisons kindly made for me, the longer paleæ of the pappus are about one third the length of the akene; the "*longiores*" in Kunth's description is therefore a mistake for *breviores*. I possess a single indigenous specimen, collected by Graham in Mexico, which belonged to the herbarium of John Stuart Mill.

T. filifolia, Lag. Nov. Gen. & Spec. 28. *T. multifida*, DC. The name of Lagasca may somewhat confidently be restored for this low species, intermediate between the preceding and the following, which better deserves the name. Like it, the longer paleæ of the pappus are strictly aristiform. The divisions of the leaves are more numerous, shorter, and less slender; the heads not so slender, mostly very short-peduncled, and disposed to be clustered.

T. micrantha, Cav. Ic. iv. 31, t. 352. This is an anisate-scented little species, paniculately much branched, slender-peduncled (except as to the later heads); the attenuate-filiform leaves with only 3 or 5 divisions, or some of the lowest and uppermost entire. It reaches the United States.

3. PECTIDIUM. Pappus bi–tricornis, nempe ex aristis paucissimis (1–4) validis corneis sæpius divergentibus.

Of EUPECTIS we have on the southern borders of the United States three species of the paleaceous division *P. prostrata*, Cav., of Mexico, *P. ciliaris*, L., and *P. linifolia*, Less., of the coast of Florida, these having come from the West Indies. Of the pauciaristate divisions, we have two short-pedunculate species which extend into Mexico; *P. tenella*, DC., and *P. angustifolia*, Torr. (the latter more commonly wanting the one or two awns, and having a paleaceous crown; and a peculiar long-peduncled species, *P. filipes*. This cannot be *P. Taliscana* or *Jaliscana*, Hook. & Arn., having very obtuse involucral bracts and only one to three (commonly two) much more rigid awns to the pappus, shorter than in any other *Eupectis*.

The West Indian species I have not the means of elucidating. But it may be doubted if *P. prostrata* is among them; and, judging from Lessing's characters, his *P. Sieberi* and *P. serpyllifolia*, with broad paleaceous pappus, cannot have been correctly referred by Grisebach to *P. humifusa*. His *P. Carthusianorum* appears to have been collected by C. Wright in San Domingo (280), and by Fendler (1975) in Venezuela. *P. Plumieri*, Griseb. is of the pauci-(3–10-)aristate division and "*P. floribunda*, Rich." is probably rightly referred to it; for an unnamed specimen from "Cuba, *La Sagra*," belongs here. *P. Swartziana*, Less., and of Griseb., I have not seen; but *P. pratensis*, Wright, in Sauvalle Fl. Cubana, 81, which has a pappus of few awns and of interposed paleolæ, probably belongs to it. *P. humifusa*, Swartz, or the plant taken for it by Lessing and by Grisebach (*Lorentea humifusa*, Less., perhaps also his *L. sessiliflora*), is well marked by its aristiform paleæ (rather than awns), 10 or 12 in number, and a few added delicate setæ outside, which, if considered to form an external series, gives Lessing's character of *Lorentea*. Moreover, it may well be the original *Lorentea*, Lag. (*L. prostrata*), "pappus paleaceo-setaceus, paleis pluribus inæqualibus," which is said to have the facies of *P. prostrata*, Cav. Note, however, that Swartz described his *P. humifusa* as "aristis 5 paleaceis basi laciniatis margine serratis."

Mexican species of *Eupectis* are: —

PECTIS PROSTRATA, Cav., depressed, with sessile heads. Schultz Bip. has sent, from a collection by Schaffner, an unpublished *P. Schaffneri*. This will probably prove to be a very narrow-leaved form of *P. prostrata*, the involucre of only 3 or 4 bracts.

PECTIS FASCICULIFLORA, DC., collected only by Hænke, is quite unknown to us.

PECTIS BONPLANDIANA, HBK., diffuse, with pedunculate heads; awns of the pappus rising from broad and short paleæ which are apt to split away, or with one or two awnless paleæ. We have it from coll. Siemann, Liebmann, and Ervendberg; the last, in Proc. Am. Acad. v. 181, inadvertently named *P. Seemanni*. That species, of Schultz in Bot. Herald, Bentham has found to be *Oxypappus scaber*.

PECTIS UNIARISTATA, DC. This, or a plant quite agreeing with the character, we have from Manzanilla, on the western coast of Mexico, collected by Xantus. The heads are slender-peduncled, and the akenes are surmounted by a cupuliform crown and a slender setiform awn, this wanting in some outer flowers.

Var. HOLOSTEMMA. Parvula; corona pappi paullo majore, arista prorsus nulla. — *P. filipes*, Schultz Bip. in coll. Liebm. no. 394, non Gray. This is neither *P. filipes*, nor is that *P. Jaliscana* (by error *Taliscana*), Hook. & Arn., to which Hemsley, following Schultz's naming, has referred it. — Consoquitla, *Liebmann*.

PECTIS ANGUSTIFOLIA, Torr. (*Pectidopsis*, DC.), with subsessile or short-peduncled heads, and a squamellate-coroniform pappus, not rarely with one or two short awns to some of the flowers, extends into Mexico as far as San Luis Potosi (*Schaffner*, 325, *Parry & Palmer*, 519, not cited by Hemsley).

Coming now to species with aristiform pappus and no crown: —

PECTIS CAPILLARIS, DC., from the southern part of Mexico, with 5-aristate pappus (presumably no paleæ or crown), is not identified.

PECTIS JALISCANA, Hook. & Arn. Bot. Beech. 296 (printed *Taliscana*, and the habitat "Jalisco" printed "Talisco"), needs to be compared with the preceding. It is not *P. filipes*, as Hemsley would have it, following an indication by Bentham. The bristles of its pappus, in two or three flowers which I have examined, though only three in number, are much more slender, and the paleaceous squamellæ are conspicuous. The published character runs "pappo radii et disci setis 3–6 aristatis basi dilatatis paleisque paucis brevissimis."

PECTIS TENELLA, DC., is a 3–6-aristate species with the aspect of *P. angustifolia*, but destitute of crown or squamellæ. Laredo is on the U. S. side of the Rio Grande; but Berlandier gathered it also in Tamaulipas, as did Gregg.

PECTIS BERLANDIERI, DC. More diffuse in the inflorescence than the foregoing (although in no. 1096 of Parry & Palmer this is glomerate); involucral bracts acuminate; pappus of 5 or 6 setiform awns, or fewer in the ray-akenes. C. Wright collected apparently a tall form of the same species in Nicaragua.

PECTIS DIFFUSA, Hook. & Arn., from the specimens of Panama, *Seemann*, which are all we possess, appears to differ from *P. Berlandieri* only (therefore too slightly) in more numerous bristles to the pappus, in the ray 5, in the disk 9 and 10. There are sometimes one or two external setulæ. So it comes nearest to *P. elongata*, and makes a transition to the next section. *P. Hænkeana*, Schultz (*Lorentea*, DC.), may be the same. Perhaps also no. 967 of Gregg's collection, which, however, is more clearly of the *Pectothrix* section, the disk-pappus of about 10 long, as many intermediate, and a few small and short exterior setæ.

PECTOTHRIX. This name is preferred to that of *Lorentea* for the multisetose or multiaristate section, because the latter, as originated by Lagasca, and one species (same as Lagasca's) of Lessing's genus, belong to *Eupectis* in the present arrangement; although, notwithstanding the words of the character, Lessing's two original species belong here. The U. S. species are only *P. papposa*, Gray, remarkable for the rather scanty and barbellate or almost plumose bristles of the pappus; and *P. longipes*, Gray; both confined to near the Mexican border, but not yet detected beyond it; for 3159 of Berlandier, referred to the latter by Hemsley, belongs to the next species.

The Mexican species which we can make out are as follows: —

PECTIS CANESCENS, HBK. Nov. Gen. & Spec. iv. 263, t. 293. *Lorentea canescens*, & *satureioides*, Less. in Linn. v. 135, & vi. 718. *L. auricularis*, *canescens*, & *satureioides*, DC. Prodr. v. 102. *Pectis auricularis*, *canescens*, & *satureioides*, Schultz Bip. Bot. Herald, 225, nomina tantum. *P. latisquama*, Schultz Bip. in herb.; Gray, Proc. Am. Acad. v. 181, var. *Berlandieri*. *P. longipes*, Hemsley, l. c., quoad Pl. Berlandier, 3159. With hardly a doubt, all these are of one species, with character of ray-pappus quite variable, more so than in the published accounts. For all our specimens (Berlandier, Ervendberg, Schaffner, Wright from Nicaragua, Parry & Palmer 1067, the latter by oversight cited under *P. Berlandieri* by Hemsley) have a pappus in the ray like that of the disk, or a little more scanty, but inclined to be deciduous. The breadth of the involucral bracts varies much. Kunth's specific name is oldest in the genus; otherwise that of *satureioides* would be preferred. The pappus is wholly setiform, about 5 innermost and longer bristles more awn-like, being distinctly stouter; the numerous others all capillary; outer ones shorter and more delicate.

PECTIS LIEBMANNI, Schultz Bip. l. c.; Hemsley, l. c. — San Augustino, *Liebmann*, 467. A most distinct species, canescent with soft

pubescence, almost tomentose. Pappus nearly of the preceding, about five of the inner bristles stronger and more aristiform.

Pectis elongata, HBK. l. c., t. 392, a common South American species, is not known from Mexico.

Of Western Central America, *P. tenuifolia* and *P. subsquarrosa* (names by Schultz in transferring from *Lorentea*) are of this group.

The West Indian *P. Cubensis*, Grisebach, is of this section, with habit somewhat of *P. humifusa*, and the stouter inner bristles of the pappus slightly broadened downward.

Pectidium. The four species here associated are *P. Coulteri*, Gray, of Arizona, and *P. multiseta*, Benth., of Lower California, forming section *Heteropectis*, Gray, Pl. Wright., — low annuals, peculiar for having the corneous pappus awns retrorsely barbed in the way of *Bidens*, — *P. punctata*, Jacq. (*Pectidium*, DC.), annual, with smooth corneous awns, and leaves almost destitute of setæ, — and *P. imberbis*, Gray, a rather tall Arizonian perennial, with no setæ to the leaves, rigid and paleaceous smooth awns and 2 or 3 short rigid paleæ, the awns not rarely obsolete. The two latter accord well in habit.

Anthemideæ.

Artemisia Klotzschiana, Bess. Revis. Artem. herb. Berol. in Linnæa, xv. 107, is the name of the Mexican species left unnamed by Hemsley, Bot. Biol. Centr.-Am. ii. 231. Coll. *Schaffner*, 275; *Parry & Palmer*, 528, 529, both from San Luis Potosi. Besser described only an incomplete specimen, collected by Schiede, the heads destitute of flowers. As Besser states, it is an annual species, with leaves dissected into small filiform lobes. It belongs to the *Abrotanum* section, and the small heads are many-flowered, ripening numerous akenes.

The following are additions to the North American species: —

Artemisia Wrightii. *Abrotanum*, microcephala, pube minuta cinerea vel canescens, pedale, foliosissima; foliis in segmenta 5 vel 7 angustissime linearia mox revoluto-filiformia integerrima pinnatipartitis; panicula stricta virgata; capitulis confertis; involucro demum glabrato. — Plains of S. Colorado and New Mexico, Wright (no. 1279, referred to in Pl. Wright. ii. 98, under the "forma tenuifolia" of *A. Mexicana*), *Greene*, *Palmer*, *Brandegee*, and *Rothrock* (no. 539), who states that it is regarded as a peculiar species.

Artemisia franserioides, E. L. Greene in Bull. Torrey Club, x. 42. A robust species of the *A. vulgaris* type, imperfect specimens of which have been referred to *A. discolor*. It is essentially glabrous throughout, for the coarsely 1–2-pinnately parted leaves, although

whitened beneath, have no evident tomentum; the heads are comparatively large and broad, in loose panicles. First collected in the mountains of S. Colorado by *Gunnison*, later by *Rothrock* in those of S. E. Arizona, and by *Greene* in S. New Mexico.

ARTEMISIA BOLANDERI. *Seriphidium*, between *A. trifida* and *A. cana*, referred to the former in Bot. Calif. i. 405: the characters indicated in the subjoined conspectus of the group. *

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* ARTEMISIA, § *Seriphidium*, Besser.

The North American species, which have much needed revision, have been arranged for the Synoptical Flora of North America essentially as follows: —

1. *Anomalous species*, mainly herbaceous, tall, with ample compound panicles, and heads more or less nodding in anthesis. — S. California.

A. PARISHII, Gray, Proc. Am. Acad. xvii. 220. Has the anomaly of sparsely arachnoid-villous akenes.

A. PALMERI, Gray, Proc. Am. Acad. xi. 79. Anomalous in having paleæ on the receptacle, subtending most of the flowers.

2. *Sage-brush*, low shrubs or suffruticulose plants of the interior dry regions, canescent; the heads erect even when young.

* Foliose-spicate; the heads solitary and sessile in the axils and all surpassed by the mostly 3-parted rigid and almost acerose leaves.

A. RIGIDA. *A. trifida*, var. *rigida*, Nutt. Trans. Am. Phil. Soc. n. ser. vii. 398. — Only sterile specimens were known to the discoverer; the flowering plant, collected by Cusick in Eastern Oregon, confirms Nuttall's conjecture that it is a peculiar species.

* * Thyrsoid-paniculate, &c.; at least the upper heads or clusters exceeding the subtending and not rigid leaves.

+ Heads comparatively small and few-flowered, mostly oblong.

A. ARBUSCULA, Nutt. l. c. Dwarf, with stout woody base but slender flowering branches, along which the heads, subtended by small leaves or bracts, are spicately or paniculately scattered: involucre 5–9-flowered: leaves on the main stem cuneate and dilated, 3-lobed or parted, and lobes sometimes again 2–3-lobed. There are two forms, both represented among Nuttall's specimens; one with more campanulate 7–9-flowered involucre; in the other this is oblong, 4–5-flowered, and the outer bracts much shorter; this occasionally occurs with a more compound and slender polycephalous panicle.

A. TRIDENTATA, Nutt. l. c. Larger, 1 to 6 feet high: leaves cuneate, 3-toothed or 3-lobed at the truncate summit, only the uppermost cuneate-linear and commonly entire: involucre 5–6-flowered; its outermost bracts short and ovate, usually tomentose-canescent. Far the most common and wide-spread *Sage-brush* or *Sage-wood*. — Var. ANGUSTIFOLIA. Leaves all narrow; lower spatulate-linear and barely 3-toothed at the rounded apex; upper entire and linear: heads rather smaller, exactly of *A. tridentata*, while the foliage is nearly that of *A. trifida*, except that it is not trifid. — Arid plains, S. Idaho and W. Nevada to the Mohave Desert and the southern borders of California.

Senecionideæ.

PSATHYROTES PILIFERA. *P. annuæ* et *P. ramosissimæ* affinis, pube quasi intermedia, sed foliis lato-rhomboideis basi cuneatis semper integerrimis pilis longissimis arachnoideis multi-articulatis ciliatis; involucro oblongo, bracteis fere linearibus erectis; acheniis (immaturis) oblongis pilis brevibus hirsutis. — S. Utah, near Kanab, *Mrs. A. P. Thompson, Parry.*

LEPIDOSPARTUM SQUAMATUM. *Tetradymia* (*Lepidosparton*) *squamata*, Gray, Proc. Am. Acad. ix. 207, & Bot. Calif. i. 408. I find it impossible to retain this singular shrub in *Tetradymia;* and the regularly imbricated chartaceo-scarious bracts, along with the acutish style-tips, give good generic characters.

CACALIOPSIS NARDOSMIA. This striking plant, which I at first named *Cacalia Nardosmia*, in Proc. Am. Acad. vii. 361, and later (viii. 631) followed Benth. & Hook. Gen. Pl. ii. 247, in referring to *Adenostyles*, finds its wholly appropriate position in the subtribe *Tussilagineæ*, between *Petasites*, of which it has the habit, and *Luina.* The style is not altogether that of *Eupatoriaceæ*, although approaching it, and the flowers are yellow. The anthers are quite entire at base, but otherwise as in *Luina.* While the specific name indicates

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A. TRIFIDA, Nutt. l. c. Low: leaves 3-cleft and 3-parted, the lobes and the entire upper leaves narrowly linear or at summit barely spatulate-dilated: involucre 3–9-flowered, its outermost bracts from oblong to lanceolate.

+ + Heads somewhat larger and broader, 7–14-flowered: inner involucral bracts more scarious: stems low, less woody.

++ Pubescence looser, furfuraceous-tomentose: inner bracts of the involucre narrow-oblong.

A. BOLANDERI. Leaves all narrowly linear, less than a line wide, acutish, entire, or with one or two small and slender apical lobes: heads numerous, densely glomerate-paniculate, 14-flowered. — Mono Pass, in the Sierra Nevada, *Bolander.* Confounded in the Botany of California with *A. trifida.*

++ ++ Pubescence fine and close throughout: involucral bracts broad.

A. CANA, Pursh. Silvery-canescent: leaves narrow, entire, or rarely one or two acute teeth or lobes: heads 5–9-flowered, canescent. — Saskatchewan to Montana and south to the Parks of Colorado.

A. ROTHROCKII, Gray, Bot. Calif. i. 618; Rothrock in Wheeler Rep. vi. 366, t. 13. Includes also specimens referred to *A. trifida* in Bot. Calif. Cinereous: leaves comparatively short-cuneate and obtusely 3-lobed, or the upper linear and entire, sometimes all lanceolate and entire: heads larger, 9–12-flowered: bracts of involucre all ovate or oval, glabrate. — California, in the eastern and southern portion of the Sierra Nevada, *Rothrock, Bolander.* S. Utah, *Ward, Parry.*

the resemblance of the herbage to that of *Petasites* (*Nardosmia*) *palmata*, the generic name here applied suggests its likeness to the original *Cacalia* of Tournefort, and in part of Linnæus, which is *Adenostyles* of Cassini.

CACALIA, L. Gen. ed. 4, 362 (excl. his own *Kleinia*, *Porophyllum*, Vaill., and Tournefort's *Cacalia*, which is *Adenostyles*). *Cacalia* (chiefly) and *Psacalium*, DC. I cannot think that the homogamous white-flowered *Senecioneæ* with deeply-cleft corollas, which Linnæus referred to *Cacalia* — and which, after restoring *Kleinia*, L., DeCandolle properly made the staple of that genus — should be combined with *Senecio*. The genus seems to be quite as good as *Emilia*, *Notonia*, *Gynura*, and some others which have been kept up. In view of the vastness of *Senecio*, it were better to limit it even somewhat arbitrarily, and, as in the analogous case of *Asteroideæ*, to make use of color; which on the whole coincides with habit, and also with geographical distribution. *Cacalia* essentially belongs to Central and North America and to Northern Asia. Only the following are more or less known to me by specimens: —

§ 1. N. E. Asian, with one North American species: corolla-lobes only half the length of the throat.

C. HASTATA, L., and some other species with still fewer-flowered paniculate heads. It is probably by a mistake that *C. hastata* has been attributed to Sitka or any part of North America. Specimens of the plant so referred by the Russian botanists, collected on Sitka, prove to belong to *Prenanthes hastata*, the *Sonchus hastatus* of Lessing, *Nabalus alatus*, Hook. Fl. Bor. Am. i. 294, t. 102.

C. SUAVEOLENS, L., of Eastern North America, with many-flowered cymosely disposed heads.

C. ACONITIFOLIA, Miq. (*Syneilesis*, Max.), with cymose heads.

§ 2. Atlantic North American species with cymosely disposed about 5-flowered heads: corolla-lobes very much longer than the throat, i. e. limb 5-parted: receptacle commonly with one or two fleshy fimbrillæ projecting from the centre. — § *Conophora*, DC.

* Leaves pedately-nerved.

C. RENIFORMIS, Muhl. in Willd. Spec. Pl.

C. ATRIPLICIFOLIA, L. Doubtless includes *C. gigantea*, Nees & Schauer.

C. DIVERSIFOLIA, Torr. & Gray. Perhaps only a form of the foregoing; but the corolla-lobes are only moderately longer than the campanulate throat.

* * Leaves 3–7-nerved or triplinerved, not lobed.

C. FLORIDANA. Has been mistaken for a form of *C. tuberosa* and for *C. diversifolia.* Accords with the latter in having the corolla-lobes little longer than the oblong-campanulate throat; is stout, with thickish leaves (apparently under the influence of brackish water); these ovate or oval, obtuse, all acute or contracted at base, coarsely and obtusely dentate; stem strongly striate-angled. — Coast of E. Florida, *Palmer*, *Chapman.*

C. OVATA, Ell., perhaps of Walter; but the brief character accords better with the next.

C. TUBEROSA, Nutt. Gen., &c.

C. LANCEOLATA, Nutt. To this or to *C. diversifolia* may be referred Walter's *C. hastata.*

§ 3. Mexican species, and one Arizonian, with cymosely disposed or rarely paniculate heads.

* Corolla-lobes linear, very much longer than the throat, i. e. limb 5-parted to near and sometimes quite down to the proper tube.

+– Akenes (as in all the preceding) very glabrous; but the herbage of these more or less pubescent.

C. DECOMPOSITA, Gray, Pl. Wright. ii. 99. *Senecio Grayanus*, Hemsl. Biol. Centr.-Am. Bot. ii. 241. The only species within the limits of the United States. Has small and few-flowered heads, and decompound-dissected leaves.

C. CERVIARIÆFOLIA, DC. *Senecio cerviariæfolius*, Hemsl. l. c. t. 51. Certainly very unlike a *Senecio;* and it is not surprising that it has been taken up as a genus, first by Zuccarini (as *Odontotrichum*), next by Kunze (*Sciadoseris*), and lastly by myself (as *Mesoneuris*); and it was left for Bentham to ascertain that it was a *Cacalia* of De-Candolle. The pappus is unusually rigid.

C. SINUATA, Llav. & Lex., DC., which Hemsley, in the work above cited, has named *Senecio calophyllus.* A well-known Mexican species, with pappus less rigid.

C. PELTATA, HBK. Nov. Gen. & Spec. iv. t. 361. *Psacalium peltatum*, Cass., DC. *Senecio peltiferus*, Hemsl. l. c. Has a soft and white pappus and large heads.

C. TABULARIS. *Senecio tabularis*, Hemsl. l. c. 248. This we know only from the specimen of Bourgeau, no. 2926; a species with thin peltate leaves and paniculate few-flowered heads of small size.

C. PACHYPHYLLA, Schultz Bip. in Seem. Bot. Herald, 310. *Senecio sclerophyllus*, Hemsl. l. c. Remarkable for its radical leaves, large, thick, reniform, reticulate-venulose.

+- +- Akenes hirsutely pubescent or papillose.

C. SCHAFFNERI. Facie *C. sinuatæ;* caule superne pedunculisque cymarum pube furfuracea cinereis; foliis radicalibus excentrice peltatis circumscriptione orbiculatis 5-partitis, segmentis bis trilobatis, sinubus obtusissimis latis, lobis oblongis; capitulis confertis (lin. 4–5-longis); involucro 5–7-phyllo 5–7-floro parum bracteolato; ovario cinereo-pubescente. — Near San Luis Potosi, *Schaffner*, no. 294, and an imperfect specimen also collected by *Parry*. Possibly this is the little-known *C. radulæfolia*, HBK.; but the leaves of that should be more finely dissected, and the peltate character is not noted.

C. CIRSIIFOLIA, Hook. & Arn. Bot. Beech. 437. *Senecio cirsiifolius*, Hemsl. l. c. I have only an imperfect authentic specimen.

C. CHIAPENSIS. *Senecio Chiapensis*, Hemsl. l. c. 338. A singular species, "growing in forests" according to the collector, thin-leaved, the lower leaves pinnately 5-lobed; heads in numerous paniculate cymes, remarkably small, only 3 lines high, 7–8-flowered; akenes puberulous. It was communicated from this herbarium to that of Kew, under another name. S. Mexico, *Ghiesbreght*.

* * Corolla-lobes of the same length as the throat: akenes glabrous: pappus-bristles barbellulate-clavellate at tip! — *Pericalia*, Cass.

C. CORDIFOLIA, HBK. l. c. 168, t. 360. *Pericalia cordifolia*, Cass. Dict. xlviii. 459. *Senecio cardiophyllus*, Hemsl. l. c. 237. Kunth was evidently mistaken in his supposition that the flowers are yellow.

* * * Corolla-lobes not more than half the length of the throat: ovaries glabrous.

C. PARASITICA, Schultz Bip. in herb. Kew & herb. Gray, cited by Hemsley, who characterizes it under the name of *Senecio parasiticus*.

C. PENDULIFLORA. *Senecio subpeltatus*, Schultz Bip. in Seem. Bot. Herald, 311, non Steud. The leaves of this remarkable species are very decidedly peltate.

* * * * Ambiguous species: corolla merely 5-toothed, flesh-colored: habit rather of *Erechthites*, but the heads homogamous.

C. PRENANTHOIDES, HBK. Nov. Gen. & Spec. iv. 167. *C. Toluccana*, DC. Prodr. vi. 325. *Senecio runcinatus*, Less. in Linn. vi. 410, therefore *Erechthites? runcinata*, DC. l. c. 295, but has no external female flowers. *Senecio mulgediifolius*, Schauer in Linn. xix. 733? *S. eximius*, Hemsl. l. c. 239. Bourgeau's no. 1086, cited by Hemsley under his (not DeCandolle's) *Erechthites runcinata*, and 1087, under *Senecio eximius*, appear to be the very same; and this author has overlooked Humboldt's plant, to which all appear to belong.

C. RUNCINATA, HBK. l. c.; DC. l. c. 327. *Senecio cirsioides*, Hemsl. l. c. 238. I have only Liebmann's specimen, no. 393. It is nearly related to the preceding, but is low, woolly, and bears fewer and larger heads.

§ 4. West Indian, of peculiar habit, shrubby: corolla-lobes much longer than the throat.

C. DISCOLOR, Grisebach, Cat. Pl. Cub.

SENECIO. The study of the North American species for the Synoptical Flora brings in a few changes in nomenclature, mostly relating to forms which have been named for collectors without revision of the whole ground; also a few new forms. Mere notes or indications may suffice for the present.

SENECIO RUGELIA. *Rugelia nudicaulis*, Shuttlew. in coll. Rugel, taken up by Chapman, is a good *Senecio*, not so near *Arnica* as might at first be thought.

SENECIO WHIPPLEANUS is the *S. eurycephalus*, var. *major*, Gray in Pacif. E. Exped. iv. 111, a species to rank next to *S. Mendocinensis*.

SENECIO HARTWEGI, Benth., belongs to a peculiar Mexican group, and was collected in a glabrous form, within our limits in S. Arizona, in 1882, by *Lemmon*.

SENECIO HUACHUCANUS, sparingly collected by *Lemmon*, at the same time, is a new species related to *S. triangularis* and *S. Andinus*. It has smaller heads than the latter, and broader leaves, the upper ones all partly clasping by a broad base, instead of attenuate.

SENECIO CRASSULUS is a name which I am obliged to give to a species of the Colorado Rocky Mountains (extending, however, to the northern part of Wyoming), the *S. integerrimus*, Gray in Am. Jour. Sci. xxxiii. 11, & Proc. Acad. Philad. 1863, 67, not of Nuttall, first collected by *Parry*. It is remarkable for its thickened involucre, becoming conical after anthesis, and multangular by the fleshy carination of its bracts; the character striking in the living plant.

SENECIO CLEVELANDI, Greene, is a well-marked Californian species, the characters of which are published in Bull. Torr. Club, while this paper is passing through the press.

SENECIO WERNERIÆFOLIUS is *S. aureus?* var. *werneriæfolius*, Gray, Proc. Acad. Philad. 1863, 68.

SENECIO PETRÆUS, Klatt, in Abh. Nat. Gesell. Halle, xv., is *S. aureus?* var. *alpinus*, Gray, Am. Jour. Sci. l. c., which must also be allowed to be a distinct species.

SENECIO CARDAMINE, Greene, Bull. Torr. Club, of the mountains

of New Mexico, is a marked species, standing next to *S. renifolius*, Porter.

SENECIO AUREUS, L., has to be in part recast. *S. Elliottii*, Torr. & Gray, appears to come into the var. *obovatus*, and *S. subnudus*, DC. is only an attenuated and usually monocephalous variety of *S. aureus*.

SENECIO NEO-MEXICANUS is a name now given to a troublesome species, collected in New Mexico by *Wright*, *Thurber*, *Henry*, *Greene*, &c., in Arizona recently by *Lemmon* and *Pringle*, and within the borders of California by *Parish*, specimens of which have been variously and dubiously referred to *S. Fendleri*, *multilobatus*, *aureus*, &c.

SENECIO LOBATUS, Pers. A delicate and depauperate state of this common species, recently collected by Palmer in Southern Texas, is the same as Berlandier's 1741, on which Klatt, in Abhand. Nat. Gesell. Halle, xv., has founded his *S. imparipinnatus*.

SENECIO MADRENSIS. Herbaceus, floccoso-tomentosus; caule 2–3-pedali e rhizomate nodoso; foliis oblongo-lanceolatis penniveniis, argute denticulatis (vel inferne dentatis), supra laxe araneoso-lanatis subtus tomento densiore incanis, radicalibus in petiolum attenuatis, caulinis basi subcordata sessili apice sensim attenuato-acuminato; capitulis sat numerosis subpaniculatis (lin. 5–6 longis) multifloris; involucro bracteolis subulatis calyculato; ligulis aut 1–2 brevibus aut nullis; corollis disci pallide flavis breviter 5-dentatis; acheniis fere glaberrimis. — On the Sierra Madre south of Saltillo, Coahuila, Palmer, 756. Remotely allied to *S. multidentatus*, Schultz Bip.

SENECIO SALIGNUS, DC. l. c. Near Parras, and in the northern part of Nuevo Leon, 743, 744, the latter a slender form, same as Berlandier's 1367, on which is founded *S. axillaris*, Klatt, l. c.

ARNICA NEVADENSIS. Semipedalis, puberula, subcinerea; foliis integerrimis oblongis plerumque obtusis subchartaceis, caulinis (paribus 2–3) sessilibus, imis radicalibusque obovatis et subrotundis longiuscule petiolatis basi aut abrupta aut subito angustata; capitulis paucis longe pedunculatis iis *A. cordifoliæ* referentibus. — California, collected several years ago on Lassen's Peak, by *Mrs. Austin*, in a cinereous form: not a little resembling *Whitneya dealbata*, the rays almost an inch long. Now again collected in the northern Sierra Nevada, altitude 9,000 ft., by *Mr. Pringle*, in a greener form, with smaller rays, some of the radical leaves abrupt at base, but none subcordate; the largest barely two inches long.

ARNICA SACHALINENSIS. Fere glaberrima; caule robusto bipedali multifoliato; foliis oblongo-lanceolatis acutis acutissime serratis nervoso-venosis basibus angustioribus connato-vaginatis (summis exceptis);

pedunculis paucis brevibus pubescentibus; involucri (pollicem alti) bracteis lato-lanceolatis; corollæ tubo hirsuto; antheris nigricantibus. — *A. Chamissonis*, Schmidt, Fl. Sachal. 151, non Less. — Sachalin Island. — Associated with *A. Unalaschensis* and *A. obtusifolia* by the anthers; very different from *A. Chamissonis*.

Cynaroideæ.

Cnicus, L. In revising this genus for the Synoptical Flora of N. America, the species have been newly arranged, and several new names have been brought in, of which some mention will here be made. The section *Echinais* nearly breaks down. The only one of our species strictly belonging to it is

C. Americanus, viz. *C. carlinoides*, var. *Americanus*, Gray, Proc. Am. Acad. x. 48, which appears to be essentially different from the Asiatic species.

C. Hallii is a new species of the group with narrow and loose involucral bracts, gradually tapering from a comparatively narrow base, the outer little shorter than the inner, — to which belong specimens variously referred to *C. Parryi*, *remotifolius*, *Hookerianus*, *eriocephalus*, and *edulis*. It is no. 310 of Hall's Oregon collection, and was also collected by Lemmon in S. W. California, and in S. Utah by Mrs. Thompson. Hall's specimen had been referred to *C. edulis*, but it has not the peculiar filiform corolla-lobes with capitellate-callous tips of that species.

C. Kamtschaticus, Maxim., of the same section, is a new acquisition, from Atkha, one of the Aleutian Islands, collected by Lieut. Turner. It is the only indigenous species we have which is not peculiar to North America.

C. Eatoni, to which is referred *Cirsium eriocephalum*, var. *leiocephalum*, with *C. foliosum* and *C. Drummondii* in part, of D. C. Eaton in Bot. King Exped., ranks between the preceding group and one to which belong *C. Andrewsii*, *Neo-Mexicanus*, *Californicus*, &c., with more imbrication to the involucre, the upper portion of the bracts more or less spreading and spinescent-tipped, and no trace of viscid or glandular line or ridge on the back.

C. Rothrockii, already published in the Proceedings, vol. xvii., follows *C. Arizonicus* in the next group, but is a very distinct species.

C. foliosus, Gray. To this (not to *C. Americanus*), according to the character, we would now refer *Cirsium scariosum*, Nutt.

C. Wheeleri is a new species, allied to the foregoing, but with the inner bracts of the involucre more conspicuously scarious-tipped, the

lower successively shorter and more appressed, the corollas crimson-purple. It was collected near Camp Apache, in Arizona, by Rothrock in Wheeler's Survey, and was referred by him to *C. undulatus*. It is his no. 293.

In the section with closely appressed-imbricated involucral bracts, only the prickle, if any, spreading, the outer successively shorter, and most of them having a viscid-glandular ridge, line, or spot on the back of the tip, some changes have been made, especially in the difficult groups to which *C. undulatus* belongs.

C. GRAHAMI, *Cirsium Grahami*, Gray, Pl. Wright. ii. 102, Hook. Bot. Mag. t. 2885, is distinguished anew. The scabrous-ciliolate edges of the principal involucral bracts give a good diagnostic character, and its habit is well marked.

C. OCHROCENTRUS, *Cirsium ochrocentrum*, Gray, Pl. Fendl. 110, is again distinguished from *C. undulatus*, taking with it some specimens which had been referred to var. *megacephalus* of the latter. Its involucral bracts are comparatively larger, flatter, broader at base, and only now and then develop a narrow viscid line or ridge on the back of the tip of some of them, and the prickle is usually longer.

C. ALTISSIMUS, Willd. To this we have to append two varieties, —

Var. FILIPENDULUS, *Cirsium filipendulum*, Engelm., of Texas, which had been confounded with *C. Virginianus*, and

Var. DISCOLOR, *C. discolor*, Muhl., differing only in the cutting of the leaves from *C. altissimus*, to which it must be united, although intermediate specimens seem to be rare.

Mutisiaceæ.

GOCHNATIA HYPOLEUCA. *Moquinia hypoleuca*, DC. Prodr. vii. 23. This shrub, which occurs along the borders of Southwestern Texas, certainly has more or less polliniferous fertile flowers; and the same is true in some specimens of the typical species of the genus, *M. polymorpha*. The style-branches of the latter, if not so exactly truncate as is figured by Heyland in DC. Mem. Comp. t. 13, are so nearly so as to offer no obstacle to the reception of the following species into the genus: —

GOCHNATIA GLOMERIFLORA. Forte herbacea, tantum puberula; foliis ovalibus, chartaceo-coriaceis concoloribus acuminatis modo *Pereziæ* rigide dentatis et reticulatis (4-pollicaribus): capitulis arcte glomeratis; glomeribus in axillis foliorum sessilibus summisve secus apicem nudum rami concatenatis; involucro 4–5-floro, bracteis lanceolato-subulatis 3–5-seriatis; floribus pallidis; styli ramis apice truncatis. —

Cuernavaca, Mexico, cóll. *Bilimek* (October, 1866), no. 512. Ex herb. Cosson.

PEREZIA, Lag. The section *Acourtia*, to which all the Mexican and North American species belong, is well marked by its homomorphous flowers, even the marginal corollas having the three-toothed outer lip little if at all longer than the two-parted inner lip. True *Perezia* consists of the South American species, with the inner lobes much shorter than the liguliform outer lip. *

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* PEREZIA, § ACOURTIA. *Key to the N. American and Mexican Species.*

§ 1. *Scaposæ.*

P. RUNCINATA, Lag. ex Don.

P. NUDICAULIS, Gray, Pl. Wright. i. 127.

§ 2. *Nanæ, ilicifoliæ, capitulis ad apicem caulium vel ramorum solitaris sessilibus.*

P. NANA, Gray, Pl. Fendl. i. 111.

P. PARRYI, Gray, Proc. Am. Acad. xv. 40.

§ 3. *Caulescentes, foliatæ, sat altæ,*

* Capitulum solitarium, pollicem altum et latum, crasso-pedunculatum in caule robusto: involucri subhemisphærici bracteæ exteriores ovatæ, coriaceæ, majusculæ, laxæ, interioribus latiores et paullo breviores.

P. WISLIZENI, Gray, Pl. Fendl. l. c., Pl. Wright. i. 126.

* * Capitula pauca vel sparsa, pollicaria vel ultrapollicaria: involucri turbinati bracteæ homomorphæ, angustæ, acutissimæ, exteriores gradatim breviores.

P. FORMOSA. *P. turbinata*, Gray, Pl. Wright. l. c., non Llav. & Lex. *Acourtia formosa*, Don, Trans. Linn. Soc. xvi. 204. *A. macrocephala* & *Trixis turbinata*, Schultz Bip. in Seem. Bot. Herald, 305, t. 55. — Northern Mexico, *Sesse & Moçino*, ex Don, *Seemann*.

P. TURBINATA, Llav. & Lex. Nov. Veg. Descr. 25. Caule inferne asperulo superne ramisque gracilibus laxe oligocephalis; foliis "coriaceo membranaceis" ovatis oblongisve amplexicaulibus creberrime spinuloso-denticulatis, majoribus 4–5-pollicaribus; ramealibus parvis, summis in bracteas lineari-subulatis transeuntibus; pedunculis gracilibus; capitulis pollicaribus; involucro 20–30-floro e bracteis circiter triseralibus lanceolatis sensim acuminatis sicco-chartaceis. — Described here from abundant specimens collected by *Schaffner* (no. 226), on a mountain-side, in the valley of Istlava, "Vallée de Mexico." Answers far better to the characters given by Llave & Lexarsa than does the preceding (to which before knowing the present species I had assigned the name), and the habitat accords better. For the *P. formosa*, as we must now name it, is known only from the northern part of Mexico.

* * * Capitula numerosa, $\frac{3}{4}$-pollicaria (8–12-flora), in thyrsum elongatum strictum foliosum aggregata: involucri bracteæ angustæ, acutissimæ.

P. THYRSOIDEA, Gray, Bot. Mex. Bound. 104. Viscidulo-puberula.

P. MOSCHATA, Llav. & Lex. l. c., if of the genus, may be placed here.

* * * * Capitula sat numerosa, vix ultra-semipollicaria, aut laxe aut glomeratim cymoso-paniculata.

Cichoriaceæ.

STEPHANOMERIA, Nutt. A revision of the genus for the Flora of North America results in some increase of the species, and a better

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+ Involucrum laxiusculum, pauciseriale, bracteis tenuibus angustis acutissimis vel acutatis sæpissime puberulo-granulosis,

++ Apice subito breviter mucronato-acutatis: capitula 10–15-flora, laxe cymoso-paniculata.

P. MICROCEPHALA, Gray, Pl. Wright. i. 127, & Bot. Calif. i. 422. *Acourtia microcephala*, DC. S. W. California.

++ ++ Sensim acutissimis: capitula laxe vel aperte cymoso- vel thyrsoideo-paniculata.

= Folia basi lata cordiformi vel auriculata pl. m. amplexicaulia, cum ramis minuta puberula vel granulosa, nunc viscidula.

P. THURBERI, Gray, Pl. Thurb. 324. Capitula 5–6-flora. S. Arizona, *Thurber*, *Lemmon.*

P. OXYLEPIS, Gray, Proc. Am. Acad. xv. 41. Capitula 12–16-flora. (*Acourtia*, Schultz Bip. in coll. Liebm.)

P. HEBECLADA, Gray, Pl. Wright. l. c. *Acourtia hebeclada*, DC. Prodr. vii. 66; Deless. Ic. Sel. iv. t. 95. Capitula 15–20-flora.

P. Humboldtii, Gray, l. c., must be a factitious species. One element, which gives the name, is *Dumerilia Humboldtii*, Less. in Linnæa, v. 13, described from an imperfect specimen of Humboldt's in the Willdenovian herbarium, the number of flowers in the head not mentioned, but the involucral bracts described as broad and rather obtuse or acute. In Syn. Comp. 408, Lessing refers to this *Proustia Mexicana*, Don. DeCandolle follows this, making the character simply "capitulis 5-floris." This is taken from Don, who describes an evidently different plant, with "involucri squamis ovato-lanceolatis acuminatis." Don's plant, from the collection of Moçino and Sesse (which was largely from the north), answers not badly to *P. Thurberi*, of which the outermost involucral bracts are "ovato-lanceolatis acuminatis." Lessing's plant, which would carry the name *Humboldtii*, may be *P. reticulata*.

= = Folia crassiora basi angustiora, haud amplexicaulia, cum ramis glaberrima, subglauca.

P. SEEMANNI, Gray, Pl. Wright. i. 127. Capitula laxe cymosa, 8–10-flora.

+ + Involucrum laxiusculum, pauci-pluriseriale; bracteis tenui-chartaceis obtusis vel obtusiusculis (nunc mucronato-acutatis), dorso lævi glabro: folia submembranacea vel chartacea, nec coriacea,

++ Lanceolata, basi angusta nec auriculata, venis parum reticulatis.

P. COULTERI, Gray, Proc. Am. Acad. xv. 40, pro parte. Caule vel ramo gracili apice nudo aperte cymoso-polycephalo: foliis bipollicaribus lato-lanceolatis parum denticulatis (infimis haud visis); capitulis (parum semipollicaribus) 7–8-floris fere omnibus pedicellatis; involucro pauciseriali, bracteis lineari-lanceolatis (semilineam latis) obtusiusculis. — Mexico, near Zimapan, *Coulter*, no. 234. — I had confounded it with a Mexican form of the next.

understanding of the characters. The changes and additions are briefly exhibited in the following synopsis.

§ 1. Alloseris (Gray, Proc. Am. Acad. vi., in part). Heads of the largest, about 12-flowered: involucre obviously imbricated: recep-

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++ ++ Folia oblonga seu ovata, reticulata, modo generis crebe denticulata vel dentata,

= Basi sessili haud angustata aut truncata aut subcordata sed parum amplexicauli: caulis erectus: rami ad apicem aperte cymoso-pleiocephali: involucrum pauciseriale, bracteis angusto-oblongis obtusis vel intimis obtusiusculis.

P. Wrightii, Gray, Pl. Wright. i. 127. *P. Arizonica*, Gray, Bot. Calif. i. 422, forma rigidior. *P. Coulteri*, pro parte, Gray, Proc. Am. Acad. xv. 40. Texas to Arizona, and a rather rigid and small-leaved form extending into Mexico to San Luis Potosi, *Schaffner*, *Parry & Palmer*, no. 547 in part.

= = Basi cordata vel sagittata amplexicauli: caulis gracilis, patenti-ramosus; ramis oligocephalis; involucrum circiter quadriseriale,

a. Campanulatum pluriflorum.

P. carpholepis (*Acourtia carpholepis*, Schultz Bip. in coll. Liebm.). Ramis flexuosis patentissimis; foliis læte-viridibus ovatis oblongisve sæpe acuminatis quandoque sinuatis; capitulis in ramulos breves foliatos paucis brevissime petiolatis semipollicaribus circiter 10-floris; involucri bracteis obtusissimis ovalibus oblongisque apice nunc purpureo tinctis. — *P. patens* var. β & var. γ, Gray, Pl. Wright. l. c. Chiapas, &c., S. Mexico, *Linden*, 439, *Galeotti*, 2001, *Liebman*, 351 in part, *Ghiesbreght*, 525, the latter in pine forests.

P. patens, Gray. Glaucescens; ramis virgato-paniculatis; foliis oblongis obtusis mucronato-denticulatis; capitulis majoribus [illegible]–[illegible]-pollicaribus pedunculos graciles bracteolatos terminantibus circa 20-floris; involucri bracteis ovato- et lanceolato-oblongis obtusiusculis. — *Acourtia formosa*, Schultz Bip. in Bot. Herald, t. 56, & *Trixis patens*, l. c. p. 315. — N. W. Mexico, *Seemann*.

b. Involucrum cylindraceum 5-florum.

P. Dugesii. Foliis ramisque flexuosis *P. carpholepidis*; capitulis ultra-semipollicaribus in glomerulum axillare sæpius brevipedunculatum basi 1–2-phyllum congestis; involucri 5-flori bracteis latiuscule linearibus mucronato-apiculatis, extimis parvulis ovato-oblongis magis acuminatis; floribus purpureis. — Guanaxuato, *Dugès*. A flowering branch only.

+ + + Involucrum arctius imbricatum, bracteis firmioribus ovalibus oblongisve obtusis nunc mucronulatis: capitula magis fasciculato-congesta plerumque sessilia,

++ 8–15-flora: folia basi sat lata truncata, subcordata, vel auriculata.

P. adnata, Gray, Pl. Wright. i. 127. Subglanduloso- vel viscidulo-puberula; caule ramisque usque ad capitula pauciuscula glomerulato-congesta æqualiter foliosis: foliis chartaceis ovatis ovalibusque, basi lata auriculis sæpius adnatis; involucro cylindraceo 8–11-floro. — *Dumerilia Alamani*, DC. Prodr. vii. 67, therefore *Perezia Alamani*, Hemsl. Biol. Centr.-Am. Bot. ii. 255. — Ghiesbreght's plant (the first to be described under this genus) has all the cauline leaves with

tacle alveolate, the alveoli fimbriolate-hirsute: pappus sordid, short-plumose: perennial.

S. CICHORIACEA, Gray, Proc. Am. Acad. l. c.

§ 2. STEPHANOMERIA proper. Heads 3–20-flowered: receptacle quite naked: pappus-bristles slender, or paleaceous-dilated only at base.

* Heads fully half an inch high, 10–20-flowered, somewhat corymbosely disposed,

+- Terminating leafy stems and branches: pappus sordid, of rather long-plumose bristles: involucre a little imbricated, i. e. having one or two bracts intermediate between the principal ones and those of the calyculus, 10–12-flowered.

S. PARRYI. Low, widely branched from the base; leaves run-

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auricles adnate-decurrent (a quarter of an inch), those of the short branches little or not at all so. Alaman's plant, described by DeCandolle (with "auriculis adnatis" in the generic character), is manifestly of the same species; and good specimens, evidently only elongated branches, have been received from Schultz (under the mss. name of *Trixis Pipitzahuac*), collected by Schaffner in the valley of Tolucca, near "Tinancinopo" and near "Venancingo" (the same doubtless cited by Hemsley, l. c. 256, under *P. fruticosa*, to which Schultz first referred it); the base of leaves little if at all adnate. My conjectural reference of this species to *P. fruticosa* Llav. & Lex., cannot be sustained, nor can DeCandolle's *Acourtia formosa* be the same.

P. PLATYPHYLLA, Gray, Pl. Fendl. 111, & Pl. Wright. l. c., is probably, but not certainly, a thinner-leaved and less rigid state of the following.

P. RIGIDA, Gray, l. c. Glaberrima, glaucescens, robusta; foliis crasso-coriaceis rigidis oblongis vel inferioribus obovato-oblongis, basi parum angusta subcordata sagittato-auriculata, summis parvulis nunc integerrimis; capitulis nudatim cymosis; involucro oblongo-campanulato 9–11- (-15-) floro.—*Acourtia rigida*, DC. Prodr. vii. 66. *A. formosa*, Hook. & Arn. Bot. Beech. 437, i. e. "*Trixis latifolia*," Hook. & Arn. l. c. 300, but char. of "spinescent scales of the involucre" does not accord: probably some admixture of specimens. *Acourtia formosa*, DC. l. c., non Don, is probably the same species. It occurs in various collections.

++ ++ Capitula 5-flora, raro 6-flora, numerosa, in glomerulis paniculata: involucri cylindracei bracteæ obtusissimæ: corollæ pallidæ: folia coriacea, oblonga, basi angusta sæpius acuta.

P. RETICULATA, Gray, l. c. 128. *Proustia reticulata*, Lag. ex Don, l. c. 200; DC. l. c. 27. A well-marked species, in various Mexican collections; said to be shrubby, but none of my specimens show it, nor have they the base of the stem.

P. FRUTICOSA, Llav. & Lex. i. 26, remains wholly doubtful. It is described as an alpine shrub, of the height of a man, with amplexicaul and roundish leaves, cylindrical and many-flowered involucre, and rose-colored corollas, the outer radiant and the inner small: so that it is a very doubtful member of this genus.

cinate-pinnatifid; pappus-bristles rather stout, naked at base, these often connate in pairs or threes.

S. LACTUCINA, Gray, l. c. Pappus-bristles slender and plumose to base.

+– +– Naked-paniculate: pappus bright white, soft, very plumose to base: involucre merely calyculate.

S. THURBERI, Gray, Pl. Thurb. 325, & Bot. Mex. Bound. 105.

S. ELATA, Nutt. Pl. Gamb. 173, from Sta. Barbara, California, remains unrecognized. Said to have 10-flowered heads, which *S. virgata*, Benth. may sometimes have; but seems to be excluded from that by "involucre and branchlets sprinkled with resinous dots."

* * Heads smaller, a quarter to a third of an inch high, rarely larger but narrow, normally 5-flowered, by depauperation sometimes 3–4-flowered, or in stronger plants occasionally 6–8- (or 10-?) flowered. — *Jamesia*, Nees, not Torr. & Gray.

+– Perennials from tortuous roots or a lignescent base, with junciform branches: pappus-bristles slender to base.

S. RUNCINATA, Nutt. Distinguishable from the following by generally stouter habit, larger heads, which are scattered along the main branches, and dull white pappus, the plume not descending quite to the base.

S. MINOR, Nutt. More slender, and leaves often filiform; the heads terminating the branchlets; the pappus bright white and very plumose down to the base. This is the *Jamesia pauciflora*, Nees in Neuwied Trav., from the Upper Missouri.

S. MYRIOCLADA, Eaton, Bot. King Exped. 198, t. 20. A much tufted and very slender-stemmed species, with scattered small heads, akenes striate at maturity; the bristles of the bright white pappus naked at the base. It has recently been rediscovered in Nevada by Mr. Marcus E. Jones.

+– +– Annuals or biennials.

++ Pappus bright white and soft; the bristles slender and plumose to the base: stems, &c. not rarely puberulent or tomentulose.

S. WRIGHTII. Seemingly biennial: stem rather slender and tall, corymbosely paniculate above, bearing naked-pedunculate terminal heads, with involucre almost half an inch long: leaves all very narrow, cauline linear-filiform: akenes contracted under the summit, smooth, as long as the long-plumose pappus. — *S. runcinata*, var., Gray, Pl. Wright. ii. 103, no. 1301. — W. Texas, *Wright*.

S. VIRGATA, Benth. Bot. Sulph. 42. *S. paniculata*, chiefly, Eaton, Bot. King Exp. l. c.; Gray, Bot. Calif. 428. *S. elata*, Nutt. Pl. Gamb. 173? Quite distinct from the following species, with which I had confounded it. The heads sometimes bear 6 or 8 flowers, or even 10 as it would seem, but commonly only 5. The akenes of the two species are similarly subclavate-oblong and rugose-tuberculate between the narrow ribs.

++ ++ Pappus sordid or fuscous; its bristles rather short-plumose down nearly or quite to the more or less paleaceous-dilated or squamelliferous base: heads 3–5-flowered, narrow, in a narrow open panicle.

S. PANICULATA, Nutt.; Torr. & Gray, Fl. ii. 743. Of more northern range than the preceding. Pappus inclined to form phalanges.

++ ++ ++ Pappus white or whitish; its bristles plumose above but naked below the middle; base more or less dilated or paleaceous, or with lateral setulose teeth or squamellæ: heads paniculate, on squamulose peduncles: akenes tuberculate-rugose at maturity.

= Pappus-bristles 9 to 18, with dilated bases not rarely connate into 4 or 5 phalanges.

S. EXIGUA, Nutt. l. c. *Hemiptilium Bigelovii*, Gray, Bot. Mex. Bound. 105. These two names were founded on extreme forms; Nuttall's upon exceedingly attenuate branches of an apparently depauperate plant, with very narrow 3–5-flowered heads. The latter name, upon the ordinary form with more robust stem, often 2 feet high, in no sense *exiguous*, the heads bearing 5 or rarely 6 to 8 flowers in an involucre of 4 or 5 lines in length. It is a species of wide range, mainly Southern.

= = Pappus-bristles 5 or sometimes 7, distinct, slender, dilated only at the very base, plumose only above the middle.

S. PENTACHÆTA, Eaton, l. c. Known only in W. Nevada (*Watson*, *Shockley*) as a low plant, and upon the edge of the desert in S. E. California, where *Parish* found a large form, 2 or 3 feet high.

§ 3. HEMIPTILIUM, Gray, in part. Heads 5-flowered, small: pappus of 4 to 6 rigid paleæ rather than awns, ciliate-plumose only toward the summit.

S. SCHOTTII, Gray, Bot. Calif. i. 427. *Hemiptilium Schottii*, Gray, Bot. Mex. Bound. 105. Found only by *Schott*, many years ago, on the Gila River.

Microseris, Don. There are a few changes and one or two additions to be made in this genus. In the section *Scorzonella* they relate wholly to the typical group, the forms of which, although they closely approach, may be distinguished as follows: —

Microseris procera is tall and robust, has the largest heads of all and the broadest leaves (excluding a large form of the next which has been confounded with it), the pappus-paleæ are found to be lanceolate (either narrowly or broadly), acute, and about one fourth the length of the awn. It is restricted to N. W. California and adjacent Oregon, is *Calais glauca* var. *procera* in Proc. Am. Acad. vii. 364, a specific name which is not kept up under *Microseris* because it is very doubtful if it can be *Hymenonema glaucum* of Hooker, and it is *M. laciniata* var. *procera*, Gray, Proc. Am. Acad. ix. 209.

Microseris laciniata, Gray, l. c., chiefly of the lower Columbia River, has smaller heads, less robust habit, shorter akenes, and pappus-paleæ deltoid or triangular-ovate, not longer than the breadth of the akene at summit, and abruptly tipped by an awn of 7 to 9 times its length.

Microseris leptosepala (*Scorzonella leptosepala*, Nutt.), from the Columbia River above the Cascades, is slender, with smaller and fewer-flowered heads; the involucre (only half-inch high) of fewer bracts, almost in two series, the inner wholly lanceolate-attenuate; paleæ of the pappus (often only 8) about a fourth or fifth of the length of the rather slender akene, ovate-lanceolate or narrower, and tapering gradually from the base upward into the awn. *Hymenonema glaucum*, Hook., only slightly characterized from an incomplete specimen, is probably a narrow-leaved form of this or of the preceding.

Microseris Bolanderi. *Calais Bolanderi*, Gray, Proc. Am. Acad. vii. 365, of N. W. California, was wrongly referred to and confounded with the preceding species in Proc. Am. Acad. ix. 209, and Botany of California. It has rather larger heads, mainly narrow involucral bracts, or the broader outermost small, and pappus-paleæ little exceeding the breadth of the akene, broadly ovate, mostly obtuse or retuse, and abruptly tipped by the slender awn.

§ Calais includes in the *Calocalais* subdivision the very long-awned *M. macrochæta*, not yet sufficiently known; also the short-awned old species, *M. linearifolia* and *M. Lindleyi*, and a new species, *M. acuminata* of Greene, which is *Calais Douglasii*, Gray, Pacif. R. Rep. iv. 113, not of DC. The species with subclavate to turbinate akenes are *M. aphantocarpha*, with its var. *tenella*, and a var. *pallealis*, which shows a tendency to pass into *M. Bigelovii*. The *Eucalais*

division contains a remarkable new species, *M. attenuata*, Greene, from the vicinity of Berkeley and of Monte Diablo, having attenuate-fusiform akenes, the slightly narrowed upper half not occupied by the seed: the species with more or less turbinate akenes are *M. Bigelovii*, *M. Douglasii*, and *M. platycarpha;* the last, which was very rare, now abundantly collected on hills around San Diego and San Luis Rey by Parry and others.

§ NOTHOCALAIS. *M. troximoides*, Gray, a remarkable plant, intermediate between *Microseris* and true *Troximon*, appears to have a rather wide range, from Montana to N. W. California.

HIERACIUM. One or two species of the section *Pilosella*, as limited by Fries in his Epicrisis, are sparingly naturalized or adventive in this country.

Of *Archieracium*, Fries, a form of *H. murorum* is also naturalized, and *H. vulgatum*, Fries, apparently occurs in Labrador. We have two leafy-stemmed species of this section, viz.: 1. *H. umbellatum*, L., an old-world species of only a northern range in this country, to which *H. macranthum*, Nutt., and *H. rigidum*, Fries, may be referred; 2. *H. Canadense*, Michx., which may be taken to include *H. corymbosum*, Fries, as to the Newfoundland plant, *H. auratum*, Fries, and, if the species is also N. European, *H. crocatum*, Fries. Even the distinctions between these two species are indefinite.

The section *Stenotheca*, as defined by Fries, contains all our other species; but in some of the Western ones the character as to the involucre does not so well hold.

1. *Atlantic Species*, all yellow-flowered and with sordid pappus. Those with columnar akenes, not tapering at summit, and loosely corymbose-cymose heads, are *H. paniculatum*, L., *H. venosum*, L. (partly), *H. scabrum*, Michx., and a species or set of forms which almost fill the seemingly most wide interval between the last two, and which, without much doubt, is *H. Carolinianum* of Fries, founded on specimens collected by Beyrich in pine barrens of Carolina; while the larger forms, having tomentose pubescence on the peduncles and involucre, may be suspected to be *H. Marianum*, Willd., a much older name. Indeed, the species is well represented by the *H. Marianum, Pulmonariæ Gallicæ subrotundis foliis*, &c., of Pluk. Mant. 102, t. 420, f. 5, whence the specific name. *H. Rugelii*, Arvet-Touvet, recently published, should be a form of the same. Fries assigns to *H. Carolinianum* "achenia longa, gracilia, sursum manifeste attenuata." So they are in our plant when half grown and not filled out, but at maturity there is no perceptible narrowing at summit.

The species of the Atlantic States having akenes fusiform-attenuate at summit, and also marked by thyrsoid-paniculate inflorescence, through most of which the main stem is continued, are only two, viz.: 1. *H. Gronovii*, L., as to the plant of Clayton and Gronovius, Flora Virginica, whence the name. The synonymy of this was mainly worked out in Torrey & Gray's Flora: but the synonym of Plukenet above referred to is to be excluded, and probably all that relates to *H. Marianum*, Willd. But it evidently is the *H. Marianum* of Fries with "anthela thyrsoidea," &c., although the phrase "achenia sursum leviter attenuata" does not so well apply to akenes the upward attenuation of which is conspicuous. 2. *H. longipilum*, Torr., the earliest name, first published without a character, and not to be superseded by *H. barbatum*, Nutt., as Tausch preoccupied that name. Var. *spathulatum* of this species, as we hesitatingly regard it, is a naked-stemmed form, which was collected by Professors Porter and Traill Green, on Tuscarora Mountain, in the Alleghanies of Pennsylvania, and provisionally named *Pilosella spathulata* by Schultz in Flora, 1862. The specimens are too young for satisfactory determination.

2. *Rocky-Mountain and Pacific Species.* — These, now considerably increased in number, may be exhibited synoptically, as follows: —

* Crinitely barbate or shaggy up to the heads, or even on the involucre, with long and whitish hairs: akenes columnar, not at all narrowed at summit: leaves entire.

H. Scouleri, Hook. — Montana and Mountains of Utah to Brit. Columbia and Oregon. The Pennsylvanian plant taken for it by Hooker, in Flora Bor.-Am., must have been the hirsute form of *H. Gronovii*. See, in respect to this species, *H. cynoglossoides*.

H. horridum, Fries, Epicr. 154. *H. Breweri*, Gray, Proc. Am. Acad. vi. 553, &c. *H. relicinum*, Fries, l. c., from Bridges's collection, is probably the same species. — Sierra Nevada, California. The name given by Fries is the earlier, but is not very appropriate.

* * Crinitely very long-villous with black or dusky glandless wool on the head and peduncles, more or less naked below: heads solitary or few.

H. triste, Cham. in herb. Willd., &c. — Aleutian Islands.

* * * Dark-hirsute and somewhat glandular about the heads, also some whitish stellular tomentum on involucre and peduncles: leaves and lower part of the stem *glabrous* or at most puberulent: alpine.

H. gracile, Hook. *H. arcticum*, Frœl. in DC., by the character is clearly of this species. *H. triste*, in part, Torr. & Gray, Fl. ii. 478.

H. triste, var. *gracile*, Gray, Bot. Calif. i. 481, with var. *detonsum*. In this variety the long and blackish hairs of the involucre are mostly or wholly wanting, and the grayish pubescence prevails. — Alaska and Brit. Columbia to the Sierra Nevada and higher Rocky Mountains down to Colorado.

* * * * Not crinitely hirsute or barbate about the heads, but mostly (as in many species) bearing long-setose hairs at base of stem and on lower leaves.

+ Flowers white: stem leafy and loosely branching, except in subalpine or depauperate specimens: leaves little if at all dentate: akenes linear-columnar: pappus sordid.

H. ALBIFLORUM, Hook. — Rocky Mountains to Brit. Columbia and California. To this without much doubt is to be referred *H. Vancouverianum*, Arvet-Touvet, Spicil. 10. At least all our specimens of Lyall's collection, distributed from Kew as "*H. Scouleri*," are of this species, and are white-flowered. A yellow color to the flowers was probably merely inferred by Arvet-Touvet from the name under which he found the plant in Boissier's herbarium. It would appear that at least three species must occur under the name of *H. Scouleri* in the Kew herbarium.

+ + Flowers yellow, 15 to 30 in the oblong-campanulate heads: stems leafy, at least below, except in one species, glabrous or merely puberulent above: akenes columnar, not at all tapering upward: pappus from sordid to dull white.

++ Leaves or many of them salient-dentate: pappus whitish.

H. ARGUTUM, Nutt. Cauline leaves above rapidly diminished in size, even into linear entire bracts: heads on elongated peduncles in a lax diffuse panicle: involucre more or less dark glandular. — Coast Mountains of California, behind Santa Barbara, &c. *Hænke, Nuttall, Rothrock, Parry.*

H. PARISHII. More equally leafy up to the narrowly oblong panicle; no glandular hairs or stipitate glands: heads short-peduncled: involucre pale, granulose-puberulent. — Rock-crevices, San Bernardino Mountains, S. E. California, *Parish Brothers.*

++ ++ Leaves all entire, or repand and denticulate.

H. RUSBYI, Greene, Bull. Torr. Club, ix. 64. Mostly tall, leafy, bearing numerous heads in a compound panicle: leaves all elongated-oblong; cauline usually half-clasping: involucre 3 lines high, pale, barely puberulent: pappus sordid. — Mogollon Mountains, New Mexico, *Rusby.*

Var. WRIGHTII. More robust, hispidulous, even up to the peduncles, sometimes a few small bristles near the tips of the involucral bracts: pappus dull white. — *Crepis ambigua*, Gray, Pl. Wright, i. 129, not Pl. Fendl. — Western border of Texas, between the Limpio and Rio Grande, *Wright.*

H. CYNOGLOSSOIDES, Arvet-Touvet. A foot or less high (either from a naked base, or more commonly from a tuft of radical leaves), simple, 2–several-leaved, setose-hirsute or hispid at base, either hispidulous or glabrous above: leaves lanceolate to spatulate-oblong, at least the lower conspicuously setose-hirsute, upper sometimes glabrous: heads few or several and corymbosely disposed: involucre 4 or 5 lines high, glandular, sometimes glandular-hispidulous: pappus whitish. — N. W. Wyoming and Montana to Washington Terr., Oregon, and N. California. — Arvet-Touvet's species (Spicil. 20) is wholly founded on Parry's no. 188 of Wyoming collection, quite immature specimens of a form so nearly on the line between this species, as here recognized, and *H. Scouleri*, as to throw doubt upon the distinctness. A better representative of the species is found in the *H. Scouleri*, Torr. & Gray, Fl. ii. 478, chiefly, described from a specimen given by Sir William Hooker to Dr. Torrey, ticketed by the former "Hieracium Scouleri, coll. Scouler." This misled the authors of the Flora of North America into a character of that species which is not congruous with the original one.

Var. NUDICAULE. Leaves all in the radical tuft, or only one or two small ones on the slender (8 to 12 inch high) and glabrous scape. — Northern portion of the Sierrá Nevada, California, *Lemmon*, *Mrs. Austin.*

+ + + Flowers apparently yellow, only 5 to 15 in the narrow and diffusely paniculate heads: involucre cylindraceous, of 7 to 9 broadly linear and obtuse principal bracts and 2 or 3 short ones, not at all glandular: akenes comparatively large, fully two lines long, chestnut-brown, slightly or at maturity not perceptibly tapering to the summit: pappus dark-fuscous: leaves obovate-spatulate, all in a radical tuft at the base of the loosely branching rather low scapes.

H. BOLANDERI, Gray, Proc. Am. Acad. vii. 365. Leaves sparsely or densely long-hirsute: no other pubescence: scape and involucre smooth and glabrous. — Mountains in Humboldt Co., N. California, *Bolander.* Head-waters of the Sacramento, *Pringle.* Sierra Co., *Lemmon.* Only in Bolander's specimens do the (immature) akenes have a tapering summit.

H. Greenei. Leaves villous-hirsute, also on both sides canescent-tomentose with stellular pubescence: scape, peduncles, and involucre cinereous-tomentose. — Pine woods, Scott Mountains, N. California, *Greene*.

+ + + + Flowers yellow, 20 or 30 in the oblong heads: akenes fusiform, tapering gradually to a narrow summit, fully as long as the white or whitish and softer pappus: stems scapiform, bearing one or two small leaves toward the base, above only subulate bracts subtending peduncles or simple branches of the panicle: leaves of radical tuft obovate to spatulate, obtuse, entire or minutely denticulate, contracted into short wing-margined petioles. — § *Chionoracium*, Schultz Bip. *Crepidispermum*, Fries, Symb. *Heteropleura*, Schultz Bip. in Flora, 1861. Transition to *Crepis*.

H. Pringlei. Strictly scapose, wholly destitute of setose hairs and of glands: leaves all radical and rosulate, obovate, densely villous-lanate both sides: scape very slender, a foot or two high, minutely soft-pubescent, as also the involucre of the few heads: immature pappus bright white. — S. Arizona, on the Santa Rita Mountains, *Pringle*, *Lemmon*.

H. Fendleri, Schultz Bip. in Bonplandia, ix. 173. *Crepis ambigua*, Gray, Pl. Fendl. 114. New Mexico, *Fendler*, *Wright*, *G. R. Vasey*. Colorado, *Parry*, *Hall & Harbour*. Somewhat polymorphous, with either reddish or blackish akenes, and the copious soft pappus sordid-whitish. The first of the subjoined forms is clearly of this species; probably the other also.

Var. discolor. Radical leaves (sometimes large) usually roundish, tinged with crimson-purple beneath: pappus nearly pure white. — Mountains of S. Arizona, *Lemmon*, *Pringle*, the latter distributed as "*Hieracium erythrospermum*, Greene, ined.," which, with name changed in publication, is really the following: —

Var.? Mogollense. Leaves narrower, not purple-tinged: bristly hairs disposed to be shorter: peduncles minutely and sparsely glandular-setulose: involucre smaller (only 5 lines high): immature akenes reddish: pappus pure white. — *H. brevipilum*, Greene in Bull. Torr. Club, ix. 64. — Mogollon Mountains, New Mexico, *Rusby*.

+ + + + + Flowers white or flesh color: akenes slender-columnar, hardly if at all narrowed upward, about the length of the bright white soft pappus: stem leafy.

H. carneum, Greene. Glaucescent, above wholly glabrous and smooth, base of stem, radical leaves, and sparingly some of the cauline,

beset with villous-setiform hairs: leaves entire, the upper narrowly lanceolate to linear: heads scattered in a corymbiform or irregular panicle: involucre campanulate, 4 or 5 lines high, pale, 15–20-flowered, of narrow lanceolate bracts: corollas light rose-color. — Mountains of New Mexico, *Greene*. Also collected long ago by Bigelow or Wright, too young. Huachuca Mountains, S. Arizona, *Lemmon*.

H. Lemmoni, Gray. Villose- or hirsute-setose up to the racemiform close thyrsus: stem simple, 2 feet high or more, very leafy: leaves lanceolate-oblong, denticulate with callous or glandular teeth; cauline partly clasping, acute; lowest oblong-spatulate, 4 to 7 inches long, tapering into winged petioles: heads (4 lines high) numerous in the oblong thyrsus, 12–20-flowered: involucre glabrous or nearly so, not glandular, not longer than the canescent-puberulent peduncles; its principal bracts narrowly linear, greenish-livid, obtuse: corollas short, seemingly white: akenes hardly 2 lines long, slender, obscurely if at all narrowed upward when mature, but manifestly so when younger: pappus not very copious, bright white. — Cave Cañon, near Fort Huachuca, S. Arizona, *Lemmon*. A species of Mexican type, belonging to the *Thyrsoidea* of Fries.

The following are Mexican species: —

H. abscissum, Less., — a Mexican species which we with probability identify, and conjecture to include *H. thyrsoideum*, Fries, a species of the same group with *H. Lemmoni*, — is said by Fries (Epicrisis, 150) to come from "Texas, ad Malpays de la Joyas," wherever that may be, and from "Alabama, *Hooker*." About which there may be some mistake; for nothing from Alabama under this name is found in the Hookerian herbarium.

H. Mexicanum, Less. in Linnæa, v. 133, probably includes all the *Intybiformia* of Fries, Epicrisis, except *H. abscissum*. It is in Schaffner, Gregg, Galeotti, and Ghiesbreght's collections. Palmer's 757 (which probably had a white pappus, somewhat discolored in drying), and Parry & Palmer's 552, 553, and even 551 (which is probably *H. niveopappum*, Fries), belong to it; and 384 of Bourgeau is very nearly the form named by Schultz *H. præmorsiforme*.

H. crepidispermum, Fries, Symb. 146, probably includes Palmer's 758, from the Sierra Madre, south of Saltillo; the flowers of which are said to be white. The pappus is white, and the akenes taper from near the base to the summit, but not very much.

Troximon alpestre. *Eutroximon*, nanum, glabrum; caudice elongato; foliis spathulatis seu lanceolatis pinnato-incisis partitisve; scapo 2–3-pollicari debili; involucri bracteis fere *T. cuspidati* sed pau-

cioribus; acheniis apice parum contractis; pappo sat molli uniformi. — Washington Territory, on Mount Paddo (formerly called Mount Adams), *Suksdorf*. Oregon on Mount Hood or in the mountains near it, *L. F. Henderson*.

TROXIMON GRACILENS. *Macrorhynchus*, inter perennes, *T. aurantiaco* proximum; floribus etiam aurantiacis; foliis sæpissime integerrimis flaccidis; scapo ultrapedali; pappo nulli; rostro tenuissimo (lin. 4–5-longo) achenio fusiformi-lineari paullo longiore. — Cascade Mountains of Oregon and Washington Terr., *Lyall*, *Nevius*, *Suksdorf*. Rocky Mountains in N. Wyoming, *Dr. Forwood*.

Var. ? GREENEI. Humilius; foliis linearibus lineari-lobatis. — Scott Mountains in Siskiyou Co., N. California, in dry open ground at 7,000 feet, *Greene*.

The beak of the akene affords very good characters in this difficult genus. I adopt the subjoined arrangement for the North American species. *

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* TROXIMON, Nutt.; Benth. & Hook.

§ 1. EUTROXIMON. Beak of the more or less linear akene either none or short and thickish, and traversed by the nerves of the body.

* No beak, the short contracted summit of the akene similar in texture to the body: involucral bracts tapering above into a slender acumination: pappus rigidulous.

T. CUSPIDATUM, Pursh, the earliest name published with a character. *T. marginatum*, Nutt.; not a bad name, for the tomentum commonly persists on the margins of the leaf.

T. ALPESTRE, Gray. Vide supra.

* * A firm and thickish lightly nerved beak, decidedly shorter than the body of the akene: involucral bracts not attenuate-acuminate.

T. GLAUCUM, Nutt., Pursh. A widespread and polymorphous species; of which the following are leading varieties: — Var. PARVIFLORUM, *T. parviflorum*, Nutt. Var. LACINIATUM, with forms on the one hand differing from *T. parviflorum* only in the laciniate-pinnatifid leaves, but in the Sierra Nevada with stouter and cinereous-pubescent forms, some approaching the next. Var. DASYCEPHALUM, to the synonyms of which in Flora N. America should probably be added *T. pumilum*, Nutt., as well as *T. taraxicifolium*. At least there are dwarf as well as large and robust forms.

§ 2. MACRORHYNCHUS. Akenes with a slender and nerveless (commonly filiform) beak.

* Perennials; the akene with acute or pointed beak-bearing apex.

+ Beak little or no longer than the cylindraceous or narrowly fusiform akene.

++ Flowers orange or reddish.

T. AURANTIACUM, Hook. *T. roseum*, Nutt., imperfectly known, seems to be

LACTUCA. Of genuine *Lactuca*, or the *Scariola* section, we appear to have five indigenous species, namely: L. CANADENSIS, L., the oldest

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only a depauperate variety of this. — Var. PURPUREUM, *Macrorhynchus purpureus*, Gray, Pl. Fendl. 114, appears to be only another form of this species.

T. GRACILENS, Gray, and var.? GREENEI. Vide supra.

++ ++ Flowers yellow.

T. NUTTALLII, Gray, Proc. Am. Acad. ix. 216, & Bot. Calif. i. 438, excl. pl. *Nevius*. To this I should refer the ambiguous forms from the Sierra Nevada, which were placed in *T. aurantiacum*, but which are near to *T. glaucum*.

T. APARGIOIDES, Less. in Linnæa, vi. 594. A small species, restricted to the coast of California. The following species has been confounded with it, the confusion beginning with Hooker and Arnott, in Bot. Beechey.

+ + Beak slender-filiform, twice to four times the length of the short-fusiform or oblong (about 2 lines long) akene: pappus soft and fine, rather flaccid: flowers all yellow. — *Stylopappus*, Nutt.

++ Pappus (whitish) about the length of the beak, and only about double the length of the akene: head from half an inch to barely an inch high: ligules elongated: involucre villous-pubescent.

T. HUMILE. *Borkhausia Lessingii*, & *Macrorhynchus Lessingii*, Hook. & Arn. Bot. Beech. 145, & 361, excl. syn.; for it is not Lessing's *T. apargioides* by the character. *Macrorhynchus humile*, Benth. Pl. Hartw. 320, a small form. *M. Harfordii*, Kellogg, Proc. Calif. Acad., a larger form. Common near the coast, from Monterey, California, to Oregon.

++ ++ Pappus (bright white) much shorter than the more elongated and capillary beak: ligules short.

T. LACINIATUM. Glabrous or with some soft loose pubescence: closed head of fruit not over an inch high: akene 2 and beak 5 to 7 lines long. — *Stylopappus laciniatus*, Nutt. (specimens too young and small), & var. *longifolius*, Nutt. l. c. *Troximon grandiflorum*, var. *tenuifolium* & var. *laciniatum*, Gray, Bot. Calif. l. c. — Common from Oregon to Brit. Columbia, and a form of it in California, which too nearly approaches the next.

T. GRANDIFLORUM, Gray, l. c., with syn.; excl. vars. Leaves hirsutely or cinereous-pubescent, or glabrate: scapes stout: involucral bracts more imbricated, lanate or tomentose when young: fruiting head commonly an inch and a half high: akenes 2 and beak 6 to 8 lines long.

* * Perennials: akenes abruptly very long-beaked from a truncate summit.

T. RETRORSUM, Gray, l. c., with syn.

* * * Annuals, small, occasionally subcaulescent: beak of akenes filiform and long. — *Macrorhynchus*, Less. Syn. 139, but akene not at all "plano-obcompressum." *Kymapleura* & *Cryptopleura*, Nutt., l. c.

T. HETEROPHYLLUM. *T. Chilense*, Gray, Bot. Calif. l. c. *Macrorhynchus Chilensis*, Hook. Lond. Jour. Bot. vi. 256, but not of Less. *M. heterophyllus* & *M. Californicus*, Torr. & Gray. Varies much in the akenes, &c.; pretty clearly distinguished from the Chilian plant or plants, by the erect involucre not villous, and shorter outer bracts. Outer akenes sometimes pubescent or villous, not

name of the *L. elongata*, Muhl. &c.; L. INTEGRIFOLIA, Bigelow (a better and perhaps nearly as old a name as *L. sagittifolia*, Ell., which is not quite certain); L. HIRSUTA, Muhl. and Nutt. (an older and quite as good a name as *L. sanguinea*, Bigelow); L. GRAMINIFOLIA, a southern species of wide extension westward; L. LUDOVICIANA, DC., a species which ranges from Dakota to Texas, and is marked by its larger heads and more imbricated and large-bracted involucre. A section, LACTUCASTRUM, is proposed for L. PULCHELLA, DC., with characters intermediate between the preceding and the following.

It is impossible not to agree with Bentham and Hooker in referring the American *Mulgedia* to *Lactuca*. Of our three species, L. FLORIDANA has an obvious but stout beak to the akene. But the akenes figured by Gærtner for this species, when he transferred *Sonchus Floridanus*, L. to *Lactuca*, do not belong to it. There is good reason to believe that these figures were made from the specimen of *Sonchus Floridanus* in the Banksian herbarium; and that, as we had long ago noted, is *L. leucophæa*.

L. ACUMINATA, *Sonchus acuminatus*, Willd. The akenes of this are beakless, and with barely an obscure neck. *L. villosa*, Jacq. Hort. Schœnbr., is an earlier but a misleading name. The plant has no villosity and commonly is devoid even of hirsute pubescence on the midrib and veins of the leaf beneath.

L. LEUCOPHÆA, *Sonchus leucophæus*, Willd., is the well-known and widely diffused species with sordid pappus. Its akenes are narrowed at summit into a neck, but have no beak. The large synonymy of this species may be still further extended; for it must be the *S. racemosus* as well as *S. spicatus* of Lamarck, *S. biennis* of Mœnch, and it may also be *S. multiflorus*, Desf.

IXERIS, Cass., which, with CHORISMA, Don, we had maintained as a genus under the former name, are referred as sections to *Lactuca* by Bentham and Hooker. But the akenes are equally and saliently costate all round, and are essentially terete. We suppose that the genus ought to stand.

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rarely utricular and enlarged, when it is *Cryptopleura Californica*, Nutt. l. c; sometimes with ribs extended into wings, and these sinuous-undulate and thickly covering the body, when it is *Macrorhynchus heterophyllus*, Nutt. l. c., in Errata made *Kymapleura heterophylla*; — two peculiar genera upon mere conditions of one species. A difference between marginal and inner akenes is not rare in *Cichoriaceæ*.

II. *Miscellaneous Genera and Species.*

Malvaceæ.

CALLIRRHOE LINEARILOBA. Facies inter *C. involucratam* et *C. digitatam*, parum hirsuta, nunc glabella; caulibus adscendentibus; foliis 1–2-pedatipartitis, segmentis lobisve linearibus vel lanceolatis; pedunculis elongatis; involucri phyllis iis *C. involucratæ* similibus sed minoribus erectis; corolla *C. involucratæ* nisi colore pallide lilacino; carpellis glabriusculis, rostro brevi e margine denticulato dorsali (modo *C. Papaveris*) libero. — *Malva involucrata*, var. *lineariloba*, Torr. & Gray, Fl. i. 226, probably, though I have not the specimens of Drummond. It is evidently Berlandier's no. 1815. It comes not rarely from Texas, is no. 85 and 86 of Palmer's Texano-Mexican collection from Lerios in Coahuila, and is now, June and July (1883) flowering and fruiting in the Botanic Garden of Harvard University. It might be supposed to be *C. palmata* of Buckley, in Proc. Acad. Philad. 1861, 449, the description of which omits all mention of an involucre, but that is said to be a prostrate plant, and the imperfect original specimen in our herbarium seems to belong to a depauperate *C. involucrata*.

Leguminosæ.

COLOGANIA LEMMONI. *C. humifusæ* similis; pube magis villosa; foliolis obovatis 2–3-plo majoribus; floribus ut videtur omnibus brevipedunculatis vel sessilibus; legumine lineari-oblongo utrinque obtusissimo polyspermo, stipiti nullo vel obscuro. — Arizona, on the high mesas of the Chiricahui Mountains, 1881, and the Huachuca, 1882, *Lemmon*. The specimens of both seasons are in fruit only, or with remains of cleistogamous flowers.

CRACCA SERICEA = *C. Edwardsii*, var. *sericea*, Gray, Proc. Am. Acad xvii. 201, now repeatedly collected, in flower and fruit, appears to hold its characters, so that we have to admit it as a species.

ASTRAGALUS REVERCHONI, Gray in coll. N. American Plants, distributed by A. H. Curtiss, no. 601 A, supplied by *J. Reverchon*, from the central parts of Texas. It was earlier collected by Wright, and by Buckley, but in insufficient specimens. Since its distribution by Curtiss under this name, it has been identified as the *Phaca cretacea* of Buckley, Proc. Acad. Philad. 1861, 452, which was first referred to *A. lotiflorus* and afterwards less incorrectly to *A. Missouriensis*, and it lies in a certain sense between the two. There is an Asiatic *Astragalus cretaceus*, so that this species may well bear the name of

our most excellent correspondent and acute botanist, *J. Reverchon*, of Dallas, Texas.

Astragalus Rattani. E radice *annua* mox multicaulis, erectus, pedalis, striguloso-puberulus; foliolis 5–7-jugis obovato-oblongis emarginatis; floribus (9–15) in pedunculo folium superante capitatis; calycis dentibus tubo campanulato paullo brevioribus corolla violacea (lin. 5 longa) dimidio brevioribus; leguminibus etiam capitato-congestis erectis fere filiformibus (bipollicaribus lineam diametro) teretibus sutura dorsali intrusa bilocellatis. — Mendocino Co., California, on prairies north of Mad River, and on Rattlesnake Creek, June, 1882, *V. Rattan*. A remarkable species of the group formerly represented only by *A. Breweri* and *A. tener*, well characterized by its long and narrow straight legumes in a capitate cluster, from three to seven maturing.

Astragalus drepanolobus. *Micranthi*, subpedalis, ramosus, striguloso-puberulus; foliolis 4–5-jugis obovatis sæpius emarginatis; pedunculis cum racemo pauci–plurifloro laxo folium superantibus; floribus albo-violaceis; calycis lobis subulatis tubo brevi-campanulato æquilongis; corollæ (lin. 4 longæ vexillo emarginato; legumine oblongo-lineari compresso obtuso falciformi estipitato fere glabro sutura dorsali introflexa bilocellato. — Washington Territory, on John Day's River at Scott's Bridge, *J. & T. J. Howell*, May, 1882. A species with much the habit of *A. multiflorus*, but with a very different falcate and completely bilocellate legume, of an inch in length, 2 lines in width; the transverse section Y-form.

Astragalus speirocarpus, Gray, Proc. Am. Acad. vi. 225, has now been received from Mr. Howell, collected on the Columbia River, fine fruiting specimens exactly like the original of Lyall, also in flower. It is different from the plant of Western Nevada and California, so named in the Botany of California, &c., which, indeed, appears to be only a variety of *A. cyrtoides*.

Astragalus Parishii. *A. oocarpo* similis, pariter flaviflorus; caule laxo bipedali; foliolis junioribus sericeo-pubescentibus; racemo minus laxo; calycis dentibus subulatis tubo dimidio brevioribus. — Common in San Bernardino Co., *S. B. & W. F. Parish*. Apparently also collected in adjacent parts of Arizona by *Palmer*. Flowers earlier than *A. oocarpus*, of San Diego Co., which is erect, stout, and fully four feet high. The legumes seem to be similar.

Astragalus bicristatus. *Podosclerocarpi*, subcinereo-puberulus; caule sat valido; foliolis 7–11-jugis sublinearibus (lin. 6–10 longis); pedunculis folium superantibus; spica aut brevi densa aut

demum elongata laxa; floribus adscendentibus (lin. 6–9 longis); calyce pilis adpressis nigris albidisque puberulo, dentibus subulatis tubo oblongo-campanulato dimidio brevioribus; corolla ut videtur alba, vexillo oblongo-ovato acutiusculo; ovario glabro; leguminibus pendulis stipitatis (stipite e calyce breviter exserto), maturis crasso-coriaceis hamato-incurvatis utrinque acutatis turgido-obcompressis suturis utrisque salientibus acute carinatis prorsus unilocularibus. — San Bernardino Mountains, S. E. California, in a cañon on the Mohave side, May, 1882, in flower, and in Holcomb Valley, August, in flower and fruit, *S. B. & W. F. Parish.*

MIMOSA LEMMONI. *Habbasia*, inter *Rubricaules* et *Acanthocarpas*, fruticosa, late ramosa, molliter pubescens; aculeis ramealibus et petiolaribus sparsis brevibus recurvis, infrastipularibus validioribus rectis geminis; stipulis spathulatis vel linearibus caducis; pinnis 4–7-jugis; foliolis 9–11-jugis (lin. 1½–2 longis) elliptico-oblongis demum glabellis subtus uninerviis et penniveniis; capitulis globosis longius pedunculatis axillaribus et ultra folia racemosis paniculam nudam efficientibus; floribus albis nunc purpureo tinctis glabris; corolla infundibuliformi breviter 5-lobo calyce triplo longiore; leguminibus angusto-oblongis rectis utrinque obtusatis (pollicem longis lin. 4 latis) furfuraceo-pubescentibus margine aculeis brevibus rectiusculis armatis. — S. Arizona, *Lemmon*, in a cañon near Fort Huachuca, in flower, with mainly racemose-paniculate heads; and Cave Cañon, in fruit, with only axillary peduncles. Near to *M. Grahami*, Gray, Pl. Wright. ii. 52, to which it might be referred except for the constant cinereous pubescence.

Caprifoliaceæ.

SAMBUCUS MELANOCARPA. Facie fere *S. Canadensis;* cymis thyrsoideo-paniculatis modo *S. racemosæ* sed tantum convexis; drupis nigris nec glaucis. — A Rocky-Mountain species which has given some trouble; first collected in New Mexico by Fendler; in the Wahsatch and (recently with fruit) in the mountains of Montana by Watson; by Brewer and Bolander in the Sierra Nevada, California; and in the Cascades of Oregon by Cusick.

LONICERA SULLIVANTII. Glaucissima, sarmentosa, parum volubilis; foliis ovalibus seu obovato-oblongis crassiusculis, iis ramorum floridorum plerisque connatis; corolla lutescente extus glabra, tubo pl. m. gibbo (intus fauceque hirsutula) semipollicari limbo vix longiore; filamentis fere glabris. — *L. n. sp.* Sullivant, Cat. Pl. Columbus, 57. *L. flava*, var. Torr. & Gray, Fl. ii. 6; Gray, Man., &c. — Central Ohio

to Illinois, Wisconsin, and Winnipeg; also in Tennessee near Nashville, and perhaps in the mountains of North Carolina; but specimen in fruit only. Introduced into cultivation many years ago at the Botanic Garden, Cambridge, from plants sent by Mr. Sullivant, thence widely distributed. In Flora of North America, &c., taken to be a variety of *Lonicera flava*, Sims. But that is a species of the Southern States only, still preserved in cultivation, with fragrant flowers; bright orange-yellow corolla, the tube slender, longer than the limb, not at all gibbous. Elliott gives a good account of it, and of its mention by Drayton, "View of S. Carolina, published in 1802, p. 64," as growing on Paris Mountain, Greenville, where it was afterward collected by Fraser and brought into cultivation. The "exposed rocky summit of Paris Mountain" is in Laurens Co., S. Carolina, where the plant should be sought anew. *L. Sullivantii* ranks between *L. flava* and *L. glauca*, Hill (*L. parviflora*, Lam.); and from the latter species the var. *Douglasii*, Torr. & Gray, may be erased. For Lindley's *Caprifolium Douglasii* is plainly *L. hirsuta*, Eaton; and many of the specimens originally referred to that variety belong to the latter species: others are merely *L. glauca* with dull purple flowers.

Rubiaceæ.

MACHAONIA FASCICULATA. Ramis calyceque puberulis, cæt. fere glabra; foliis lineari-spathulatis eveniis in axillis fasciculatis subsessilibus parum semipollicaribus; floribus 4-meris; calycis lobis lato-ovalibus membranaceis tubo dimidio brevioribus; corolla subrotata majuscula. —Mexico, Coulter, no. 1167.

OLDENLANDIA GREENEI. Glabra, parvula; caule paniculato-ramoso e radice annua exili; foliis spathulato-linearibus obtusis basi attenuatis; floribus in dichotomiis et secus ramos breves nudos cymæ sessilibus; corollæ albidæ lin. 1–2 longæ subinfundibuliformis tubo calycis lobos parum superante; capsula quadrangulato-hemisphærico vel parum turbinato calycis dentibus subulatis paullo longiore; seminibus angulatis fere lævibus.—Pinos Altos Mountains of New Mexico, *E. L. Greene* (149), 1880. S. Arizona, in Ramsey's Cañon, 1882, *Lemmon.*

CRUSEA, Cham. As *Mitracarpus** is characterized by the circumscissile dehiscence of the fruit, the upper part with the persistent calyx-lobes falling off, so are *Richardia** and *Crusea* by the falling off entire

* If we are constrained by the laws of nomenclature to go back to the Linnæan name *Richardia*, adopted from Houston, for a genus intended to commemorate a Dr. Richardson of those days, notwithstanding the faulty and misleading form, we may more cordially restore the original *Mitracarpus* for the genus which

of the somewhat gamophyllous calyx-limb from the fruit at the maturity or at the dehiscence of the latter. It is by an oversight that the limb of the calyx in *Crusea* is characterized as persistent in DC. Prodr. iv. 567, and in Benth. & Hook. Gen. ii. 144. The original character in the Linnæa, v. 165, "Achænia . . . . spermopodio persistenti plano apice affixa, sub maturitati sponte desilientia, integro calycis limbo tum seorsim deciduo," is explicit in this regard, and is correct. By all the essential characters we must refer to *Crusea* two small-flowered species of somewhat different habit, namely: —

CRUSEA SUBULATA.* *Borreria subulata*, DC. Prodr. iv. 543. *Spermacoce subulata*, Pavon ex DC.; Hemsl. Biol. Centr.-Am. Bot. ii. 60. Besides the casting of the calyx-limb at dehiscence, the two carpels in this species leave in the axis a conspicuous carpophore, of their own length, narrow, and subulately bifid to near the middle, so that the plant could belong neither to *Spermacoce* nor to *Diodia*, and the carpels dehisce by a chink down the whole length of the commissural face. This species, not uncommon in Mexico, was collected by *Wright* in Arizona; at least seeds were gathered by him from which plants were raised in the Botanic Garden of Harvard University in the year 1852; and recently it has been collected in the same district by *Lemmon.*

CRUSEA ALLOCOCCA. Referring this to *Crusea*, I shall not add unnecessarily to the synonymy by imposing this specific name. It is *Diodia tricocca*, Torr. & Gray, Fl. ii. 30, and *D. tetracocca*, Hemsl. l. c. 56, t. 40, f. 10–15, and the carpels vary from three to four, both in Texan and in Mexican specimens, although the lesser number prevails in Texas. The species varies greatly in the width of the leaves and in pubescence; both the fruits and the herbage are sometimes quite smooth and glabrous, sometimes puberulent or hirsute, and in no. 1187 of Palmer's collection even hispid. The carpels are dorsally very convex, ventrally flattened, and either closed or with the thin commissural face more or less ruptured in dehiscence; the carpophore weak, and

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has been inadvertently written *Mitracarpum* by all succeeding botanists, except Bentham (in Bot. Voy. Sulph.) and myself, who endeavored to improve it into *Mitracarpium*. By referring to the original publication of Zuccarini's name and character in Roem. & Schult. Syst. Mant. iii. 210, it will be seen that the "*Mitracarpum*" and the "*Mitracarpum scabrum*" there cited are accusatives (as the form of the word should sufficiently indicate); and the index to the volume accordingly gives us "*Mitracarpus scaber*." No increase of the synonymy should come from the remanding of the genus to its proper gender.

* The "*Crusea subulata*" in Hemsley, Biol. Centr.-Am. Bot. l. c. 57, is a slip of the pen or a misprint of *Crusea subalata*, Hook. & Arn. Bot. Beech. Voy. 431.

very attenuate upward. The ticket of Berlandier's no. 2382 = 952, bears the record "fl. flammei." But surely the corolla in this and the preceding species is white or nearly so. No stable characters are found to distinguish Hemsley's *Diodia tetracocca* from the Texan plant, long ago described as *D. tricocca*.

The following Cuban genus is to be added to the tribe.

NODOCARPÆA, Nov. Gen. *Spermacocearum*.

Calycis limbus nullus. Corolla epigyna rotata, tripartita (an semper), lobis ovatis æstivatione valvatis. Stamina 3, sinubus corollæ inserta, brevissima: antheræ ovales. Ovarium obovato-globosum, biloculare. Ovula in loculis solitaria, septo medio peltatim affixa, amphitropa, micropyle infera. Stylus brevi-filiformis: stigmata 2, obtusa. Capsula globosa, parum didyma, tenui-coriacea, corolla marcescente diu apiculata, dicocca, coccis demum solutis clausis, axi nullo interposito. Semen nitidum, ovale, plano-convexum vel meniscoideum, ventre sulcatum. — Herbula Cubensis, tenella, flaccido-decumbens et radicans; stipulis interpetiolaribus tenuibus parum vaginantibus subulato-attenuatis pinnato- vel ramoso-setiferis; foliis ovatis subsessilibus costa excepta enerviis oppositis, summis alaribusque quaternis vel ternis flores 1–4 parvos sessiles involucrantibus; corolla "alba." (Νωδός, toothless, καρπός, fruit.)

Nodocarpæa radicans. *Borreria radicans*, Griseb. Cat. Pl. Cub. 142. — Forma hirta, foliis caulibusque pilis longis undique hirsuta. — Forma glabrescens, magis tenella, pilis fere destitula. — Western part of Cuba, on the moist banks of rivers and lagunes, *C. Wright*, no. 2774.* The difference between the hairy and the glabrate forms is

* Part of the distribution consists of a slender and radicant form of no. 2769, *Diodia simplex*, Swartz, according to Grisebach, viz. his *Borreria simplex*, but truly a *Diodia*.

Spermacoce rubricaulis, Wright in Sauvalle, Fl. Cubana, 71, no. 3590 of distribution, is identical with no. 2768, named by Grisebach *Borreria spinosa*, Cham. & Schlecht.; and it may be a slender form of that species, but it wants the spinulose murication which gives the name.

Spermacoce Domingensis, 2770 of same collection, *Borreria*, Griseb. Cat. Pl. Cub. 141, appears to be *S. parviflora*, a narrow-leaved form, which occurs also in Florida.

Spermacoce richardsonioides, Wright, l. c., 73, founded on *Richardsonia muricata* Griseb. l. c. (no. 2776), is, as Grisebach had concluded, a dicarpellary *Richardia*.

Diodia lippioides, Griseb. Cat. Pl. Cub. 141 (2762 of Wright's collection) is remarkable — although Grisebach overlooked it — for having a solitary calyx-lobe! This persists on one of the cocci, while the other has none at all.

so striking, that, since the collector's original tickets indicate at least three separate stations and different dates of gathering the specimens, I was disposed to regard them as distinct species; but a few scattered hairs on the glabrate form render the separation unadvisable. The larger leaves of this little plant are 3 lines, the smaller only 2 lines in length. Capsule half a line at most in length.

GALIUM. The revision of this genus for the North American Flora brings in few additions and few changes that have not already been indicated. The following are the principal.

GALIUM TEXENSE is a name proposed to take the place of *G. Californicum*, var. *Texanum*, Torr. & Gray, Fl., which was later referred to the Mexican *G. uncinulatum*. Our plant better accords with the character of *G. obstipum*, Schlecht., but still seems to be distinct from the Mexican species, one or more, to which it is nearly related, and it is an annual. The form *Texense* is used because Scheele introduced a *G. Texanum*, founding it on a mere form of *G. virgatum*, and badly describing it.

GALIUM KAMTSCHATICUM, Steller, is a species allied to *G. circæzans*, which ranges from the mountains of Lower Canada (where it was recently collected by Dr. Allen of New York), and the higher mountains of New England (where it is known as *G. Littellii*, Oakes, *G. circæzans*, var. *montanum*, Torr. & Gray), to those of Oregon and Washington Territory, Unalaska, Kamtschatka, and Sagalien. One cannot understand why Ledebour referred this plant to *G. obovatum*, HBK., a species figured as having unicostate leaves and inhabiting Equatorial America.

GALIUM ARKANSANUM. This is *G. latifolium β*, Torr. & Gray. It has, indeed, the flowers and inflorescence of that most distinct species, but has more scabrous-hispidulous and narrow *unicostate* leaves. Besides Dr. Engelmann's specimen, it is known to us by a linear-leaved form collected at the Hot Springs of Arkansas by *Dr. Foreman* of Washington.

GALIUM MATTHEWSII. *Trichogalium*, inter *G. angustifolium* et *G. stellatum*, glabrum, læve, frutescens; caulibus paniculato-ramosissimis; foliis rigidis oblongo- vel ovato-lanceolatis parvis, superioribus apice cuspidato-acutatis; setis fructus immaturi rigidulis breviusculis. — Arid district in Inyo Co., California, *Dr. Matthews*.

GALIUM BOLANDERI, Gray, Proc. Am. Acad. vii. 350, proves to have been founded on a male plant of the white-berried species which, collected in fruit by Sir Joseph Hooker and myself, was published as *G. margaricoccum*, Gray, l. c. xiii. 371.

Valerianaceæ.

VALERIANA ARIZONICA. — Glabra, semipedalis; caulibus e rhizomatibus repentibus crassiusculis erectis præter radicalia 2–4-phyllis; foliis succulentis, radicalibus ovatis integris subintegerrimis (pollicaribus) paucisve secus petiolum longiorem 2–4-lobulatis, caulinis subsessilibus 3–5-partitis; cyma glomerato-congesta; corolla semipollicari tubulosa, tubo in faucem sensim ampliato limbo quintuplo longiore. — Arizona; in mountains near Prescott, *Palmer*, 1876; Santa Catalina Mountains, at 7,000 feet, *Lemmon*. In character somewhat between *V. Sitchensis*, Bong., and *V. pauciflora*, Michx.; with the elongated corolla of the latter.

VALERIANA SORBIFOLIA, HBK., is an accession to the North American flora, a form of it, mostly with unusually large and broad leaflets, having been collected in a cañon of the Huachuca Mountains, S. Arizona, by *Lemmon*, 2713, 2728.

VALERIANELLA. In Torrey and Gray's Flora of North America, the long-flowered species from Arkansas, forming the section *Siphonella*, were judged to effect such a transition to *Fedia* that, following Gærtner and Vahl, *Valerianella* was reduced to *Fedia*. This was not well; for *Valerianella* is not only the older name, but one of numerous published species, while there is hardly more than one true *Fedia*. But the junction under the name of *Valerianella*, Tourn., Haller, &c., must needs be made, and *Plectritis*, DC., should be included. There is now a species of the latter which has a spurless corolla; the rudiment of the spur, in the form of a small saccate or conical protuberance, is not uncommon in several of our Valerianellas, notably in *V. amarella*, *V. Nuttallii*, and even *V. longiflora*; while the Betckea section has the wings of the fruit replaced by nerviform rudiments of the sterile cells. The limb of the corolla is not quite regular in the *Siphonellæ*, is either nearly regular or decidedly bilabiate in different species of *Plectritis*; so that nothing but the diandrous instead of triandrous flower is left to characterize *Fedia*. Whatever view be taken of that genus, it is evident that the American forms (*Siphonella*, *Plectritis*, *Betckea*, the latter already united) all fall into one genus.*

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* VALERIANELLA, Tourn., Haller, Mœnch: spec. Am. Borealis.

§ 1. VALERIANELLA propria. — *Valerianella*, Krok, Monogr. Valer.; Benth. & Hook. Gen., excl. § *Siphonella*.

* Inquilina, subcæruliflora: fructus loculus fertilis dorso suberoso-incrassatus.

V. OLITORIA, Pollich. *V. cœrulea*, Aikin in Eaton, Man. Bot.

Lobeliaceæ.

PARISHELLA, Nov. Gen. *Cyphiearum.*

Calyx 5-fidus, tubo campanulato adnato lobis spathulatis foliaceis breviore. Corolla subrotata, calyce brevior, profunde fere æqualiter 5-fida. Stamina 5, a corolla libera: filamenta (basi tantum discreta) in tubum gracilem apice inflexum connata: antheræ liberæ, nudæ, ovales, loculis introrsum dehiscentibus. Ovarium biloculare, multi-

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* * Regione orientali indigenæ, albifloræ.

+ Fructus pl. m. triangularis, loculis sterilibus fertili minoribus ad angulam obtusiorem: corollæ tubus gracilis fauce limboque subæquilongus.

V. CHENOPODIFOLIA, DC. — *V. triquetra,* Shuttleworth in Flora, 1837, 211, t. 8. *V. Fagopyrum,* Walp. Repert. ii 527. *Fedia chenopodifolia,* Pursh, Fl. ii. 727. *F. Fagopyrum,* Torr. & Gray, Fl. ii. 51. Shuttleworth, having Virginian specimens of this species, suspected it to be the plant briefly described by Pursh. Having examined the original in the Sherardian herbarium, I can confirm this judgment.

V. AMARELLA, Krok, Monogr. Valer. 55, t. 2, f. 14. *Fedia amarella,* Lindheimer, Engelm. in Pl. Lindh. ii. 217. Texas; named from a peculiar bitterness of the herbage, which is wanting in the associated species, according to Lindheimer. A saccate gibbosity, at the base of the throat of the corolla, is in some flowers almost spur-like.

+ + Fructus oblongo- seu ovato-tetragonus, antice inter loculos steriles contiguos fertili non latiores nec majores sulcatus.

V. STENOCARPA, Krok, Monogr. *Fedia stenocarpa,* Engelm.

V. RADIATA, Dufresne, non DC.

+ + + Fructus loculi steriles ampliati aut inflati aut valde divergentes fertili multo majores.

V. WOODSIANA, Walp., Krok, l. c. *Fedia Woodsiana,* Torr. & Gray, Fl. ii. 52.

Var UMBILICATA. Fructus maturus loculis sterilibus introrsis confluentibus vesiculosis centro profunde umbilicatis, ore subrotundo. — *V. umbilicata,* Krok. *Fedia umbilicata,* Sulliv. *F. radiata,* var. *umbilicata,* Porter in Am. Nat. vi. 387, t. 108.

Var. PATELLARIA. Fructus quasi meniscoideus, basi apiceque emarginatus, loculis sterilibus maxime divergentibus demum applanatis alæformibus nunc marginibus pl. m involutis. — *V. patellaria,* Krok. *Fedia patellaria,* Sulliv. *F. radiata,* var. *patellaria,* Porter, l. c. 387, t. 106.

§ 2. SIPHONELLA, Krok. — *Fedia* § *Siphonella,* Torr. & Gray, Fl. ii. 50. Species 2 Arkansanæ.

V. LONGIFLORA, Walp. Corollæ tubo filiformi purpurascente lobis albis 3–4-plo longiori juxta basim gibbere parvo instructo; fructus loculo fertili apice lato-obtuso. — *Fedia longiflora,* Torr. & Gray, l. c.

V. NUTTALLII, Walp. Corollæ albæ tubo lobis duplo longiori versus medium gibbere parvo instructo; fructus loculo fertili angusto-apiculato. — *Fedia Nuttallii,* Torr. & Gray, l. c.

ovulatum: stylus filiformis: stigma depresso-capitatum, bilobum, exannulatum. Capsula turbinata, infera, polysperma, vertice inter calycis lobos persistentes operculatim dehiscens, operculo late conico stylo apiculato cum corolla marcescente demum deciduo. Semina globosa, fere lævia.

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§ 3. Plectritis, Lindl. Bot. Reg. t. 1094. *Plectritis* & *Betckea*, DC. *Plectritis*, Benth. & Hook. — Spec. Amer.-Occidentalis.

* Fructus cum ala circumdata meniscoideus, nunc acetabuliformis, dorso obtuse angulatus: cotyledones faciei ventrali parallelæ: flores parvi.

V. macrocera. — *Plectritis congesta*, var. *minor*, Hook. Fl. i. 291. *P. macrocera*, Torr. & Gray, Fl. ii. 50. Runs into various forms; the spur of the corolla sometimes as long as the body, not rarely rather short; the tube below its origin either slender and stipe-like or short, sometimes very short. So the specific name is not always appropriate.

* * Fructus dorso carinato-angulatus: cotyledones contrariæ, i. e. faciei ventrali accumbentes.

+ Alæ fructus sat evolutæ, pl. m. introrsæ.

++ Corolla *ecalcarata*, parva; fauce lato-infundibulari, basi hinc gibbere parvo mammæformi nunc evanido instructa, limbo æqualiter 4-partito, segmento postico emarginato vel bifido: fructus dorso acute carinatus, ala lata basi introrsa superne patente.

V. anomala. — Wet grounds on the Columbia River and near it, *Howell*, *Suksdorf*. This appears to produce also some wingless fruit.

++ ++ Corolla basi calcarata.

V. congesta, Lindl. Bot. Reg. t. 1094. *Plectritis congesta*, DC. Corolla usually 4 lines long and with exserted genitalia. Fruit salient into an acute angle dorsally, but the edge not so acute as in the preceding, or even slightly bevelled. *P. brachystemon*, Fisch. & Meyer, Ind. Sem. Hort. Petrop. 1835, Suppl., according to an authentic specimen of the cultivated plant, is a small-flowered form of this species, with downy fruit. But the character, "flores quadruplo minores albos et stamina non exserta," points to *P. macrocera*.

V. aphanoptera. *V. samolifoliæ* persimilis, præter fructus paullo majorem, aliis angústis incurvis inconspicuis. — Wet hillsides along the Columbia River, Klikitat Co., Washington Terr., *Suksdorf*. And an imperfect specimen, collected on "Columbia Plains" by Nuttall, distributed as *Plectritis capitata*, appears to be the same.

+ + Alæ fructus subæqualiter triquetri nullæ. — *Betckea*, DC.

V. samolifolia. — *Betckea samolifolia*, DC. l. c. 642. *B. major*, Fisch. & Meyer, Ind. Sem. Petrop. l. c. (5) 30. *Plectritis samolifolia* & *P. major*, Höck in Engler, Bot. Jahrb. iii. 37. Raised in 1835, from seed collected at the Russian colony Ross, in California; specimens differing from the Chilian only in somewhat larger size, — of small consequence in an annual. Recently collected by *H. N. Suksdorf*, in low grounds on the Columbia River, "without doubt indigenous," says this excellent collector and acute observer. The preceding may prove to be a mere state of this species; and in any case the value of *Betckea* even as a section is destroyed.

Parishella Californica. Herba exigua, monocarpica, glabella; foliis spathulatis cum floribus axillaribus brevipedunculatis in collo rosulato-confertis mox proliferis, ramis depressis inferne nudis; corolla alba. — At Rabbit Springs, in the Mohave Desert, May, 1882, *S. B. & W. F. Parish*. It is interesting indeed to add to our Flora a second genus of the very peculiar tribe to which *Nemacladus* of Nuttall belongs. The habit of this little plant is quite unlike that of its nearest relative; but the floral structure is very similar. The comparatively large and foliaceous calyx-lobes, completely adnate ovary, and the short and regular almost rotate corolla, furnish good generic characters; and above all there is the subapical circumscissile dehiscence. The capsule is indeed a pyxidium, the broad and low conical apex within the calyx-lobes falling away as a lid. The plant forms a small slender-rooted tuft, close to the ground, of spatulate entire leaves, which are only a quarter or half an inch long, subtending short-peduncled flowers: the calyx-lobes, of one or two lines in length, soon much surpass the white corolla. In the manner common to many of these desert annuals, three or four radical branches are sent out with a long naked internode, and at apex a tuft of leaves and flowers like the primary one, these again proliferous, &c. As there is already a genus *Parishia* in another part of the world, I have to adopt a different form in naming this small but very interesting plant in honor of the discoverers, my invaluable correspondents, two brothers of great botanical zeal and acuteness, who in the few years of their residence in San Bernardino have wonderfully opened up the botany of that portion of California, having already sent us many new plants of that region, in excellent specimens, and most kindly in every way assisted us and other botanists. A brief note upon this plant was published in Coulter's Botanical Gazette, vii. (1882) 94.

Ericaceæ.

Gaultheria. The two forms of *G. Myrsinites*, which are indicated in the Synoptical Flora of North America, now known to us in abundant specimens from various stations, and recently by complete specimens with notes from W. N. Suksdorf of Washington Territory, are manifestly of two species, with the following distinguishing characters: —

Gaultheria Myrsinites, Hook. Cæspitoso-depressa, undique glabra; foliis ovalibus vel rotundatis plerumque semipollicaribus; corolla depresso-campanulata calycem parum superante. — Alpine and subalpine meadows and damp hillsides, in the Rocky Mountains

from British America to Colorado and Utah, and westward on the higher Cascades and Sierras from Washington Territory to the borders of California.

GAULTHERIA OVATIFOLIA. Major, dodrantalis; ramis adsurgentibus calyceque pilis mox ferrugineis pilosis; foliis lato-ovatis etiam subcordatis pollicaribus immo sesquipollicaribus magis serrulatis; corolla campanulata calycis lobis acutioribus duplo longiori. — Wooded banks of streams and cañons of the Cascade Mountains, borders of British Columbia, Washington Territory, and N. Oregon, coll. *Lyall*, *E. Hall*, *S. Watson*, *W. N. Suksdorf*.

Asclepiadaceæ.

METASTELMA ARIZONICUM. Caulibus fere filiformibus e basi lignescente ultrapedalibus filiformibus puberulis; foliis crassiusculis angusto-linearibus acutis basi abrupta parum latiore petiolatis eveniis marginibus mox revolutis; cymulis paucifloris in axillis subsessilibus; corolla lin. 2 longa campaniformi 5-partita, lobis lanceolatis obtusiusculis intus villo brevi retrorsum barbatis; coronæ squamis 5 attenuato-linearibus stigma superantibus basi columnæ antheris paullo breviori insertis. — Arizona, on hills near Tucson, May, 1883, *Pringle*.

ASCLEPIAS CURTISSII. Juxta *A. obovatam* collocanda; caule puberulo 1–3-pedali; foliis glabellis oppositis ovalibus brevi-petiolatis subtransverse lineato-venosis internodiis 2–3-plo longioribus (sesquipollicaribus); umbellis subsolitariis brevi-pedunculatis; floribus pauciusculis viridulo-albidis; cucullis subhastato-lanceolatis rectis arrectisque gynostemium longe superantibus supra basim marginibus latis tenuibus inflexis, cornu infra medium orto falcato-incurvo lato apice adsurgente; antherarum alis latissimis angulo acuto; columna brevissima. — Eastern part of S. Florida, *A. H. Curtiss*, 1879. (This has recently been published in the supplement to a re-issue of Chapman's Flora of Southern U. S., 643.)

ASCLEPIAS LEMMONI. Procera, pilis patentibus multiarticulatis pubescens vel in caule hirto-villosa: foliis magnis (5–10-pollicaribus) oppositis ovalibus obtusissimis basi subcordatis subsessilibus; pedunculis folio paullo brevioribus; umbella multiflora; pedicellis uncialibus villoso-hirtis; floribus inter maximos; petalis (lin. 5 longis) ovatis flavo-viridulis glabris; columna staminea brevi; cucullis albidis (lin. 4 longis) antheras longe superantibus ovato-sublanceolatis superne patentibus versus basim obtuse bidentatis et cornu oblongo plano obtusissimo instructis, costa callosa purpurascente; folliculis pubescentibus. — S. Arizona, near Fort Huachuca, on slopes in Tanner's Cañon, in

fruit and flower; also in coll. of 1881, fruit only, in Rucker Valley, *Lemmon*.*

Loganiaceæ.

BUDDLEIA PRINGLEI. Inter *Globosas* et *Verticillatas*, Benth. quasi media; ramis ramulisque glabris; foliis nascentibus furfuraceo-canescentibus, adultis glabris viridibus oblongis vel lato-lanceolatis obtusiusculis subintegerrimis (parum bipollicaribus) basi attenuatis breviter marginato-petiolatis; capitulis plurifloris interrupte spicatis, plerisque subsessilibus nudis approximatis, infimis remotioribus in axillis foliorum magis pedunculatis; corollæ tubo e calyce albo-tomentuloso vix exserto lobis 2–3-plo longioribus, fauce hirsutula; ovario apice tomentoso; stigmate incrassato, lobis cohærentibus. — Arizona, in fields near Tucson, May, 1883, *Pringle*.

Gentianaceæ.

GENTIANA FORWOODII. *Pneumonanthe*, *G. affini* sat similis; corollis subdimidio minoribus; caulibus adsurgenti-diffusis (6–12-pollicaribus) usque ad apicem crebrius subæqualiter foliosis; foliis oblongis imisve ovatis summis nunc angusto-lanceolatis; calyce subcampanulato brevi (lin. 2–3-longo) prorsus edentato margine sphacelato aut inæqualiter crenato-bilobo aut hinc fisso quasi spathaceo. — High meadows of the Wind River Mountains, *Dr. W. H. Forwood*, U. S. A.; coll. August, 1882, a low form, with stems little over a span high, equably leafy to the very top, the leaves 6 or 7 pairs, uppermost closely subtending the three or four clustered flowers and of equal length; the specimens bearing small resemblance to *G. affinis*. Again collected in August, 1883, in abundant specimens, of 6 to 12 inches in height, with longer upper internodes, narrower upper leaves, short-spiciform or racemiform inflorescence of few or several flowers, and so displaying its near relationship to *G. affinis*, the calyx-teeth of which, generally large, are variable, and in some flowers a part or even all of them obsolete. The corolla in this new species is decidedly smaller, not over three fourths of an inch long, narrow, and with shorter and rounder lobes, these little surpassing the plical appendages. None of the very many specimens, from several stations,

* In Lemmon's collection (fruit in 1881, flowers in 1882) we have *Asclepias glaucescens*, HBK., or, if the species are different, *A. elata*, Benth. Pl. Hartw. It is evidently the latter, which appears to be common in Mexico; but we suppose the plant described and figured by Kunth is only a somewhat smaller-flowered and narrower-leaved variety of the same species.

shows the least vestige of lobes or teeth to the calyx. The rare specimens of *G. affinis* in which these are obsolete in some of the flowers have the more ample corolla of that species.

Gentiana Bigelovii. *Pneumonanthe*, *G. affini* proxima; foliis angustis crassioribus, superioribus linearibus; floribus spicato-congestis; corolla vix pollicari vel minore cylindracea extus scabrida et lineis prominulis crenulato-scabris notata, lobis brevibus lato-ovatis plerumque erectis plicarum lobulis bifidis duplo longioribus; stipite capsulæ brevi fistuloso; seminibus ala angusta crassiuscula cinctis. — *G. affinis*, Torr. Bot. Mex. Bound. 157, &c. — Colorado to Arizona. In S. Arizona, on a high plateau, at 9,000 feet, *Lemmon*, 1882. This has passed as an extreme form of *G. affinis*, but it decisively differs by its oblong rather than funnelform corolla, with shorter lobes, and by the salient crenulate or roughened ridges which in the bud externally border the infolded plicæ; the stipe is shorter and broader, and completely fistulous, so that some of the seeds fall into it even to the bottom. No. 1567, coll. *Wright*, from New Mexico, is exactly like Lemmon's plant. Shorter and stouter specimens were collected in 1853 by *Bigelow* in the Sandia Mountains (although not enumerated in Pacif. R. Rep. iv.); and these are matched by Colorado specimens, no. 468, *Hall* & *Harbour*, 1862, and no. 329, coll. *Greene*.

Polemoniaceæ.

Lœselia (Giliopsis) Havardi. Perennis, humilis, diffuso-ramosissima, pilis multiarticulatis crispatulis cinereo-villosa; foliis plerumque pinnato-3–5-partitis, lobis filiformibus cuspidato-mucronatis; floribus sparsis nudis brevi-pedunculatis; corolla alba hypocraterimorpha, tubo lobis ovalibus obtusis mucronulatis calyceque paullo longioribus, fauce parum obliquo; filamentis æqualiter insertis corollæ lobos æquantibus valde declinatis et superne involuto-incurvis; ovulis numerosis. — W. Texas, on the Rio Grande near Presidio del Norte, *Dr. N. Havard*, 1881. Another of those Gilioid species which tend to confuse *Lœselia* and *Gilia*. But if the strongly declinate and even involute filaments of the present species do not exclude it from *Gilia*, both genera will in the end have to be combined with *Polemonium*.

Hydrophyllaceæ.

Phacelia Popei, Torr. & Gray, in Pacif. R. Rep. ii. 172, t. 10, is to be re-established, and to be referred to the subdivision with "calyx more or less setose-hispid." The seeds, which are pretty well figured,

are short-oval and roughened by muriculate toothing of the reticulations and some rugosity. The recent distribution of Curtiss, as *P. glandulosa*, no. 2128* in his sets of United States plants, belongs to it. Also Wright's no. 1578.

PHACELIA PARISHII. *Eutoca*, *P. demissæ* et *P. pulchellæ* proxima, seminibus oblongis prioris, viscidula; foliis ovalibus repando-crenatis; spica densiflora longiuscule pedunculata; calycis lobis lato-spathulatis corolla parum brevioribus capsulam ovali-oblongam circa 20-spermam æquantibus; stylo hirsuto apice brevissimæ bilobo. — Near Rabbit Springs, of the Mohave Desert, May, 1882, *S. B. & W. F. Parish*. A span high, the earliest peduncles nearly radical. Fructiferous calyx fully 3 lines long, thickish, foliaceous; the pedicels very short. Corolla campanulate, blue in the dried specimens, only 2 lines long, the internal appendages obscure or none. Seeds fully half a line long.

PHACELIA PACHYPHYLLA. *Microgenetes*, pube brevi viscidissima, robusta, subpedalis, patenti-ramosa; foliis succulentis siccitate crasso-coriaceis rotundatis sæpe subcordatis fere integerrimis, inferioribus 1–2-pollicaribus cum petiolo percrasso æquilongo, superioribus subsessilibus; spicis brevi-pedunculatis sæpius geminatis densifloris; calycis lobis lato-linearibus corollam campanulatam lin. 2–3 longam cæruleam capsulamque subglobosam polyspermum æquantibus; seminibus ovali-oblongis semilineam longis. — Dry alkaline lakes, near Calico Mines, Mohave Desert, May, 1882, *S. B. & W. F. Parish*. A most peculiar species, to be placed at the end of the *Microgenetes* section. Internal appendages of the corolla small and narrow, connected at the base with the short dilated base of the filaments.

PHACELIA ORCUTTIANA. *Microgenetes*, inter *P. Cumingei* Chilensem et *P. Fremonti* collocanda, viscido-pubens, subpedalis, erecta; foliis pinnatifidis, lobis brevibus integerrimis; spicis elongatis densifloris; corolla rotato-campanulata ochroleuca vel alba fauce flava calyce duplo longiore, plicis vix ullis; capsula ovali-oblonga sepalis angusto-spathulatis subæquilonga 12–14-sperma; seminibus ovalibus favoso-corrugatis. — Mountains of Lower California near the U. S. border, *Charles N. Orcutt*.

Mr. Orcutt likewise collected in Lower California a well-marked and very viscid species of the *Eutoca* section, which was described under an appropriate name; but being informed that it was some years ago named by Dr. Kellogg from specimens collected by Dr. Veatch, and is about to be published in California, I leave it without further notice.

Borraginaceæ.

Eritrichium molle. Inter *Eueritrichium* et *Krynitskiam*, depresso-diffusum, caulibus elongatis basi repentibus radicantibus ut videtur perennans, pilis laxis crebris molliter hirsutum vel potius villosum; foliis elongato-lingulatis (plerisque bipollicaribus); spicis demum elongatis subsolitariis ebracteatis villosis; pedicellis calycis segmentis lineari-oblongis (fructiferis laxis) dimidio brevioribus; corolla alba, limbo lin. 3 lato; nuculis (lineam longis) trigono-ovatis modice obcompressis dorso vix carinatis grosse areolato-rugosis intus superne carinatis, inferne triente cicatrice ovato-lanceolata gynobasi brevi-oblongo affixis. — Sierra Valley, California, on alkaline wet flats and borders of ponds, *Lemmon*, 1874 to 1883, at length with good fruit. In the Botany of California (i. 528) this is referred to as perhaps a decumbent form of *E. Kingii*, of which the fruit was characterized, partly from the original account, and partly from immature nutlets of the present plant, or of *E. Kingii ?* collected by Lemmon in the same district, but on sandy dunes. The plant now described is very different from *E. Kingii*, of which I have only now seen, through Prof. Eaton's kindness, the mature, muricate-rugose fruit. Evidently the present plant is most nearly related to *E. Scouleri*, although the scar of the nutlets is wholly introrse.

Eritrichium Cooperi. *Eueritrichium*, *Myosotidea*, *E. Californico* et *E. Scouleri* affine, patenti-diffusum e radice ut videtur annua, setis patentissimis brevibus undique hispidum; foliis subsucculentis fere omnibus alternis linearibus (semipollicaribus); caulibus longe racemifloris inter flores brevissime pedicellatos hinc inde bracteatis; corollæ rotatæ limbo 2–3 lin. lato albo in centro flavo; calyce fructifero aperto sesquilineari profunde 5-partito; nuculis ovatis trigono-obcompressis obtusiusculis glabris ventre reticulato-rugosulis dorso transverse rugosis, cicatrice brevi sublineari. — Mohave Desert, S. E. California, at Camp Cady, *Dr. Cooper*, 1860–61; Rabbit Springs, May, 1882, *S. B. & W. F. Parish*, near to and in water.

Eritrichium oxygonum. *Krynitzkia*, *E. muriculato* proximum; cyma terminali pedunculata sæpius triradiata; nuculis calycis lobis oblongo-lanceolatis obtusiusculis paullo brevioribus subtriquetris *Fagopyri* instar ex ovata subacuminatis, dorso leviter convexo parce muriculato, angulis lateralibus acutis, faciebus lævibus planis, angulo ventrali sulco sat lato gynobasi elongato-subulatæ usque ad apicem inserto. — Limb of the rotate corolla 2 lines broad, with conspicuous appendages in the throat. Nutlets a line long. — S. E. California, on hills bordering the Mohave Desert, *Pringle*, 1882.

Eritrichium micromeres. *Krynitzkia*, erectum, subpedale e radice ut videtur annua, pilis patentibus brevibus hirsutum vel hispidum; caule gracili ramosissimo; foliis parvis (lin. 3–6 longis) linearibus integerrimis; spicis filiformibus pedunculatis demum sparsifloris; floribus minimis; corolla inconspicua; calyce etiam fructifero vix ultra semilineam longo setis uncinatis hispidissimo, lobis lanceolatis obtusiusculis fructum parum superantibus; nuculis ovato-trigonis acutangulis dorso demum muriculato-scabris, sulco ventrali latiusculo basi subito dilatato. — Near Santa Cruz, California, 1881, *Marcus E. Jones*.

Echidiocarya ursina. Depressa, ramosissima, hispida; floribus fere omnibus folioso-bracteatis; corollis minimis; nuculis breviter stipitatis distinctis lævibus (haud muriculatis) lineis leviter prominulis reticulatis. — Common on dry slopes of Bear Valley in the San Bernardino Mountains, S. E. California, *S. B. & W. F. Parish*, 1879 and 1882. This and the nearly related *E. Californica* effect nearly a transition to the *Plagiobothrys* section of *Eritrichium*.

Convolvulaceæ.

Ipomœa Thurberi, Gray. *Pharbitis*, præter folia quandoque utrinque hispidulo-pubescentia glaberrima; radice perenni tuberosa; caulibus gracilibus procumbentibus; foliis cordato-hastatis acuminatis (lobis sæpius bifidis) vel superioribus 5–7-fidis lobis triangulari-lanceolatis divergentibus; pedunculis unifloris petiolo brevioribus supra bracteolas clavato-incrassatis; sepalis (pollicaribus) elongato-lanceolatis sensim acuminatis æqualibus glaberrimis; corolla ultra-bipollicari purpurea e tubo gracili superne infundibuliformi; stigmate trilobo; ovario triloculari (nunc 4-loculari?); seminibus furfuraceo-puberulis. — Syn. Fl. ii. 212. — Southern Arizona, now collected in flower, on limestone rocks, by *J. G. Lemmon*. And the species proves to be of the *Pharbitis* group.

Ipomœa cuneifolia. Exigua, glabra; caule gracili e cormo globoso enato decumbente; foliis cuneatis brevi-petiolatis e basi 5–9-nervatis apice inciso-dentatis, dentibus 3–7 lanceolatis; pedunculis filiformibus unifloris folium subæquantibus; sepalis (lin. 3–4 longis) oblongis obtusis, omnibus vel exterioribus secus costam processibus mollibus insigniter muricatis; corolla purpurea vix pollicari infundibuliformi; capsula parva 4-valvi disperma, seminibus tantum puberulis. — S. Arizona, in Tanner's Cañon, near Fort Huachuca, *Lemmon*. — The larger leaves of this remarkable species are hardly an inch long. The calyx resembles that of *I. capillacea*, Don (*I. muricata*, Cav.),

but the muricate processes are larger. Two distinct forms of the latter species are noted by Mr. Lemmon, one erect, the other diffuse-procumbent, the corms also different; and he suspects that *I. cuneifolia* may be a form of one of these, with the leaflets confluent into a cuneate simple leaf.

IPOMŒA LEMMONI. *I. leptotomæ*, Torr. peraffinis, prorsus glaberrima; caule debili vix volubili e cormo vel tubere crasso oblongo; segmentis foliorum pedatorum angusto-linearibus elongatis (majoribus bipollicaribus) tenuibus; pedunculis filiformibus unifloris petiolum gracilem haud superantibus; pedicello perbrevi bracteolis setaceo-subulatis parum longiori cum calyce glaberrimo; sepalis oblongis acutis submembranaceis, exterioribus costa vix prominula parce tenuiter muriculata; corolla angusta bipollicari; fructu adhuc ignoto. — Southern Arizona in the mountains near Fort Huachuca, *J. G. Lemmon.**

Solanaceæ.

SARACHA UMBELLATA, DC. Cat. Monsp.? Sweet, Brit. Fl. Gard. t. 85; G. Don, Syst.; Dunal in DC., but "Peru" cited as the country by Sweet, and subsequent authors following the lead. *Atropa umbellata*, Roth, Cat. ii. 26 (no habitat); Jacq. Hort. Schœnbr. t. 493, who gives "Mexico." A common Mexican species (the fruit edible and sold in the markets), described under several names, such as *S. Jatomata*, Schlecht., and probably his *S. allogona;* also *S. glabrata*, and probably *S. diffusa*, *laxa*, and *conspersa*, Miers, *S. Miersii*, Dunal. It came to be taken for Peruvian through some confusion with the nearly related *S. procumbens*, Ruiz & Pav. First collected now within the U. S. by *Lemmon*, in cañons near Fort Huachuca, S. Arizona. His specimens have peduncles shorter than the pedicels, which is not usual.

MARGARANTHUS LEMMONI. Decumbenti-ramosissima, magis foliosa; foliis omnibus integerrimis nec repandis; calyce profundius 5-dentato, dentibus tubo nunc dimidio brevioribus; corolla alba supra tubum brevissimum campanulato-urceolata, ore breviter obtuseque 5-lobo. —

* *I. tenuiloba*, Torr. Bot. Mex. Bound. 148, — of which a specimen exists only in the Torrey Herbarium, and which was accidentally omitted in Syn. Fl. N. Amer., — is another species of this group. It has filiform leaflets, hardly thicker than the petiole, the latter shorter than the stout peduncle; sepals oblong; corolla as large as that of *I. sagittata;* root unknown. Torrey's remark on no. 1617, Wright, is to be excluded. That plant is *I. longifolia*, and the whole sentence belongs to the account of that species on p. 149, and was accidentally misplaced.

S. Arizona, in Cave Cañon, near Fort Huachuca, *Lemmon*. Resembles *M. solanaceus*, but with somewhat different habit, and with corolla so little urceolate that, if this species only were regarded, it would hardly be generically separated from *Physalis*. *P. minutiflora*, taken up by Dunal from Moçino and Sesse's drawings (but accidentally omitted from the *Calques des Dessins*), may be the same; but the "foliis repandis" would apply better to *M. solanaceus*, the "pruinosis" to neither.

Scrophulariaceæ.

Pentstemon rubescens. *P. dasyphyllo* nimium affinis, minutissime pruinoso-puberulus; foliis angustissime linearibus glabratis; thyrso aperto, ramis patentibus sæpius trifloris; sepalis ovatis plerumque subito acuminatis glanduloso-puberulis; corolla sesquipollicari (ut videtur incarnata) e tubo brevi ventricoso-ampliata, lobis brevibus latis consimilibus, vel antico paullo longiore; antherarum loculis (ut in *P. dasyphyllo*) turgido-ovatis, valvulis ciliato-denticulatis. — S. Arizona, near Fort Huachuca, in Tanner's Cañon, *Lemmon*.

Pentstemon cæsius. *Saccanthera*, inter *P. gracilentem* et *P. Roezli*, subpedalis e basi parum lignescente; foliis coriaceis glaucis integerrimis subeveniis, plerisque rotundis (semipollicaribus) in petiolum æquilongum marginatum subito decurrentibus, superioribus paucis spathulatis vel sublanceolatis sessilibus; thyrso laxifloro; sepalis oblongis pedicellis pedunculisque pruinoso-glandulosis; corolla (fere ¾-pollicari) tubulosa sursum parum ampliata purpurea seu violacea, limbo brevi intus glabro; filamento sterili filiformi glaberrimo. — S. E. California, on rocks in the San Bernardino Mountains, coll. Parry & Lemmon (1876, no. 304), *W. G. Wright*, 1880, *S. B. & W. F. Parish*, 1880 and 1882. A well-marked species, of which the materials were until now scanty. It has probably been somewhat distributed as a form of *P. lætus* or of *P. Roezli*, from which it widely differs both in the foliage, the glaucous hue, and the narrow corolla.

Buchnera pilosa, Benth., var. Arizonica. Forma hispidula, nunc paniculato-ramosa. — Southern Arizona near Fort Huachuca, *Lemmon*, 1882. A form of the commonest and the most variable Mexican species.*

* The American species north of the Isthmus have never been well determined. The subjoined memoranda may contribute in some degree to a better understanding of them.

CASTILLEIA CINEREA. E grege *C. pallidæ* et *C. viscidulæ*, multicaulis, spithamæa ad subpedalem, molliter cinereo-pubescens; caulibus adscendentibus conferte foliosis; foliis parvis (semipollicaribus sesquilineam latis) lineari-lanceolatis suberectis integerrimis, superioribus trifidis, floralibus 3–5-fidis spathulato-dilatatis luteo-tinctis viscido-glandulosis; spica brevi densa; calycis segmentis bipartitis, lobis linearibus; galea corollæ brevi-oblonga truncata tubo quadruplo breviore labio obtuse tricrenato 3–4-plo longiore; stigmate disciformi maximo. — S. E. California, on rocky hillsides of Bear Valley in the San Bernardino Mountains, 1882, *S. B. & W. F. Parish.*

CASTILLEIA PLAGIOTOMA. (§ Calyx normaliter bilabiatus, labiis latis, postico emarginato, antico parum longiore obcordato-bifido.) Bipedalis e radice crasso perenni, gracilis, ramosa, inferne glabella; spicis inferne sparsifloris cum bracteis calycibusque cinereo-pubescentibus vel tomentulosis; foliis imis angusto-linearibus, superioribus trifidis lobis linearibus, floralibus 3–5-fidis; calyce oblongo, labiis tubo paullo

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Ser. *A.* Calyx-teeth short, equal, broadly triangular or ovate, not surpassing the turgid-ovate mature capsule: corolla-tube pubescent or puberulent: stem strict, mostly simple, naked and pedunculiform at summit.

B. AMERICANA, L. Leaves broad and dentate: calyx-teeth acute. The common Northern species.

B. ELONGATA, Swartz. Leaves narrower, less dentate or entire: calyx-teeth obtuse. — W. Indies, Florida, Texas, and doubtless in the eastern part of Mexico.

Ser. *B.* Calyx-teeth short, triangular, unequal (the mouth oblique), barely equalling the gibbous capsule: corolla-tube glabrous.

B. OBLIQUA, Benth. in DC. Prodr. x. 498. Mexico. To this belongs a plant from Orizaba, *Botteri*, 94, and a part of the specimens distributed under no. 177, 365, from coll. *Ervendberg*, near Tantoyuca.

Ser. *C.* Calyx-teeth subulate, equal or nearly so, in fruit surpassing the straight but somewhat oblique capsule: stems simple or branched, leafy up to the infloresence.

* Corolla-tube pubescent.

B. PILOSA, Benth. Bot. Sulph. without char., & DC. Prodr. l. c. under *B. lithospermifolia.* Sometimes rather stout and 2 feet high, sometimes low and slender: radical leaves obovate or oblong, upper lanceolate to linear, the larger ones not rarely with a few teeth: tube of the corolla barely twice the length of the calyx, appressed-pilose outside. — *B. elongata*, var. *pilosa*, Cham. & Schlecht. in Linn. viii. 245. *B. lithospermifolia*, Benth. in DC. l. c., mainly; Gray, Proc. Am. Acad. v. 186 (pl. Ervendberg) in part. *B. elongata*, Hemsl. Biol. Centr.-Am. ii. 457, at least in great part. — Mexico, in various forms; among them coll. *Bourgeau*, 884 in part, 2900, *Schaffner*, &c., S. Arizona, *Lemmon*, 2830, the var. *Arizonica*, indicated above. *B. lithospermifolia*, HBK., is from S. America, and is said to have a glabrous corolla with tube thrice the length of the calyx, the

brevioribus corolla lutea vix brevioribus; galea recta tubo æquilonga, labio brevissimo. — On the Mohave Desert, S. E. California, May 18, 1882, *Pringle*. Remarkable for the anterior and posterior calyx-lobes.

ORTHOCARPUS IMBRICATUS, Torr. in Watson, Bot. King, 458, is a good species and was very wrongly referred to *O. tenuifolius*, Benth. in Syn. Fl. 300. It was characterized on poor specimens, which seemed to have a minutely uncinate tip to the galea; this, however, the numerous specimens now in hand do not have.*

CORDYLANTHUS PRINGLEI. *Adenostegia*, inter *Tetrastemones oligospermeas;* glabellus, elatus, ramosissimus; ramis gracillimis diffusis; foliis lineari-filiformibus integerrimis, imis pubescentibus ultrapollicaribus, ramealibus semipollicaribus glabris; bracteis flores 2–5-natos ad apicem ramulorum confertos subtendentibus flabelliformibus 3–5-lobatis brevibus; sepalis subæqualibus oblongis superne parce glanduloso-scabridis corolla brevi-oblonga lutea (lin. 4–5-longa) parum brevi-

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latter in fruit shorter than the capsule. This character as to the corolla (and also in the foliage) is exhibited by no. 8255 coll. Spruce on the Oronoco, distributed by Bentham as "*B. elongata*," but its calyx appears to be quite glabrous.

* * Corolla-tube quite glabrous: stem very slender: leaves all narrow linear to filiform.

B. MEXICANA, Hemsl. Bot. Biol. Centr.-Am. ii. 457. Rather tall: tube of the corolla rather conspicuously exserted; the expanded limb a third to a half inch broad: calyx-teeth slender-subulate, in fruit spreading. — N. W. Mexico, *Seemann*. Mexico, *Hartweg*, 100 (referred to *B. lithospermifolia*, in Benth. Pl. Hartw., and by Hemsley!; Orizaba, *Botteri*, 583, 794, form with smaller corolla.

B. DISTICHA, HBK. Nov. Gen. & Spec. ii. 340, ex char. Very slender: leaves mostly filiform: flowers small: tube of corolla less exserted: calyx-teeth shorter, triangular-subulate, erect or little spreading in fruit. *B. tinctoria*, Bertol. Fl. Guatemal. 426? — S. Mexico, *Ghiesbreght*, 8260. The original habitat Santa Fé de Bogotá? The plant here taken for this species was collected in that district by *Holton*, 585; also Venezuela, *Fendler*, 848.

* The three species of the first division of true *Orthocarpus*, in Syn. Fl. N. Amer., are better characterized as follows: —

+ Corolla and bracts rose-purple or purplish; the latter wholly chartaceo-scarious and reticulated in age.

O. IMBRICATUS, Torr. l. c. Usually slender and branched from the base; stem and leaves minutely puberulent: the rounded bracts either naked or sparsely ciliate at base, entire or usually with a single pair of short small lobes: calyx very short, its broad lobes with a pair of short and small subulate teeth: corolla hardly half inch long; lip and galea of equal length; the latter usually quite destitute of uncinate apex: anther-cells oval. — *O. tenuifolius* mainly, Gray, Bot. Calif. i. 577, partly, Syn. Fl., mainly. — Common in the mountains of the northern part of California and adjacent part of Oregon.

oribus. — California, on dry hills in Lake Co., August, 1882, *Pringle.* — A most distinct species, with short and obtusely lobed bracts and a short corolla.

CORDYLANTHUS, § 4. DICRANOSTEGIA. Calyx monophyllus (posticus), bipartitus, segmentis ovatis acuminatis uninerviis.

CORDYLANTHUS ORCUTTIANUS. Humilis, hispidulus, crebre foliosus; foliis etiam floralibus pinnatipartitis, lobis linearibus; floribus glomeratis; corolla flavescente, labiis æqualibus latis; filamentis glabris; antheris longiorum bilocularibus, loculo infero remoto fere casso, breviorum gracilibus anthera sterili bipartita aureo-hirsuta instructis. — Lower California, about 70 miles below the U. S. boundary, *H. C. Orcutt* and son. The specimens are only 6 inches high, mostly branched from the base, but it probably grows taller. It forms a peculiar section in the genus; the calyx evidently consisting of a posterior deeply two-parted sepal.

Lentibulariaceæ.

UTRICULARIA OCCIDENTALIS. Facie inter *U. minorem* et *U. intermediam;* caulibus foliisque prioris; scapa spithamæa 3–5-flora; pedicellis post anthesin subpatentibus; corollæ labio superiore palato inferioris rotundati (lin. 3–4 longi latique) paullo longiore, calcare latoconico acutiusculo lin. 2 longo adscendente. — Washington Territory, in Falcon Valley, *W. N. Suksdorf,* coll. 1880, 1883.

Verbenaceæ.

VERBENA ARIZONICA. *V. canescenti* proxima, e radice perenni multicaulis diffuso-patens, humilis, canescenti-hirsuta; foliis omnibus

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O. PACHYSTACHYUS, Gray. Low, stouter and the inflorescence densely imbricate-spicate, puberulent and above somewhat hirsute-pubescent; bracts (inch or more long), with one or sometimes two pairs of elongated lateral lobes, middle lobe oblong: calyx half the length of the corolla, deeply 2-cleft, and the divisions cleft to the middle into subulate lanceolate lobes: corolla over an inch long; galea with uncinate tip, surpassing the lip: anther-cells linear-lunate, acute at base. — Thus far collected only by *E. L. Greene,* in Siskiyou Co., California.

+ + Corolla yellow (as rightly said Pursh); bracts below more herbaceous, less reticulated the summit of the oblong middle lobe purple.

O. LINEARIFOLIUS, Benth. (*Bartsia tenuifolia,* Pursh.) Strict, branching at summit, sparsely hirsute or hispid, especially the margins of the 3–5-lobed bracts: calyx half the length of the corolla, its lobes with a pair of elongated subulate teeth: corolla two-thirds inch long, narrow; galea with small uncinate tip a little surpassing the lip: anthers oval. — Rocky Mountains in Montana to Oregon, first coll. by Lewis and Clark.

brevipetiolatis bis 3–5-partitis circumscriptione obovata, lobis crebris oblongo-lanceolatis (lin. 1–2 longis), pube hirsuto-sericea; spicis angustis confertifloris; bracteis subulato-lanceolatis calycem æquantibus; nuculis oblongis intus granuloso-scabris. — S. Arizona, in cañons near Fort Huachuca, *Lemmon.*

Labiatæ.

Monardella Pringlei. E grege *M. lanceolatæ* et *M. undulatæ*, e radice annua ultrapedalis, mox multicaulis; foliis oblongo-lanceolatis acutiusculis basi attenuatis vix petiolatis integerrimis plerumque pollicaribus ramisque tenuiter puberulis, venis obscuris; bracteis villosis lato-ovatis subito tenuiter acuminatis plurinervatis albidis purpureo tinctis, venulis fere nullis; calycis dentibus subulato-lanceolatis acutis intus extusque hirsutis; corolla læte purpurea. — Sandy ridges, near Colton, San Bernardino Co., S. E. California, *Pringle.*

II.

CONTRIBUTIONS FROM THE ZOÖLOGICAL LABORATORY OF THE MUSEUM OF COMPARATIVE ZOÖLOGY AT HARVARD COLLEGE.

No. I.—ON THE DEVELOPMENT OF THE POSTERIOR FISSURE OF THE SPINAL CORD, AND THE REDUCTION OF THE CENTRAL CANAL, IN THE PIG.*

By William Barnes.

Presented June 13, 1883, by Alexander Agassiz.

It is well known that the anterior and posterior fissures of the spinal cord are not produced in the same manner. While the formation of the anterior fissure results from a comparatively simple process of growth and enlargement in the region of the anterior horns, the production of the posterior fissure appears to be dependent on more complicated changes. More or less intimately connected with its formation is the disappearance of a portion of the original lumen of the neural tube. Whether, however, the posterior fissure is "a part of the original neural canal separated from the rest of the cavity by a median coalescence of the side walls," as claimed by Foster and Balfour; or whether the atrophy of a portion of the canal is only a necessary antecedent to the formation of the fissure; or whether, finally, its obliteration may be considered as causally connected with the appearance of the fissure, — appear still to be questions which have not received their definite answer.†

It was with a view to gaining additional information on these points that the following investigations on the pig were undertaken.

Literature.

Clarke, J. L.

'62. Researches on the Development of the Spinal Cord in Man, Mammalia, and Birds. Philos. Trans. Royal Soc. London, 1862, pp. 911-938, Pl. XLV.-XLVIII.

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* The following investigations were made in the Embryological Laboratory of the Museum, under the supervision of Dr. E. L. Mark.

† Balfour ('81, p. 844) says, "The exact mode of its formation appears to me to be still involved in some obscurity."

Balfour, F. M.
'80. A Treatise on Comparative Embryology. Vol. I. xi + 492 pp., 275 figs. London: Macmillan & Co.
'81. Same. Vol. II. xi + 655 + xxii pp., 429 figs.
Bidder, F., und Kupffer, C.
'57. Untersuchungen über die Textur des Rückenmarks und Entwickelung seiner Formelemente. viii + 121 pp., 5 Taf. Leipzig.
Foster, M., and Balfour, F. M.
'74. The Elèments of Embryology. Part I. xix + 266 pp., 71 figs. London: Macmillan & Co.
Kölliker, A.
'61. Entwickelungsgeschichte des Menschen und der höheren Thiere. vi + 468 pp., 225 figs. Leipzig.
'79. Same. 2d edition. xxxiv + xvi + 1033 pp., 606 figs. Leipzig.
Loewe, L.
'80. Beiträge zur Anatomie und zur Entwickelungsgeschichte des Nervensystems der Säugethiere und des Menschen. Bd. I. Die Morphogenesis des centralen Nervensystems. xiii + 126 pp., 18 Taf. Leipzig.
Lubinoff.
'74. Embryologische und histogenetische Untersuchungen über das sympathetische und centrale cerebrospinal Nervensystem. Virchow's Archiv f. Physiol., Bd. LX. pp. 217–273, Taf. VII. and VIII.
Remak, Robert.
'55. Untersuchungen über die Entwickelung der Wirbelthiere. vi + xxxviii + 195 pp., 12 Taf. Berlin: G. Reimer. 1850, 1851, 1855.
Waldeyer, W.
'76. Ueber die Entwickelung des Centralkanals im Rückenmark. Virchow's Archiv f. Physiol., Bd. LXVIII. pp. 20–26, 6 Holzschn.

Nothing is said concerning the formation of the posterior fissure by the earlier writers on the development of the nervous system. Even Remak ('55) does not enter into this subject.

Bidder and Kupffer ('57, p. 114) say that in the chick embryo, between the eighth and ninth days of incubation, the white substance of the posterior columns has grown around the posterior segment of the cord, so that only a small gap, the posterior fissure, remains between the columns. They do not attempt to pursue further the process which gives rise to this fissure.

In the first edition of Kölliker's *Entwickelungsgeschichte des Menschen*, etc. ('61, p. 262), incidental to an account of the gradual obliteration of the dorsal part of the central canal, there is a short description of cross sections of the cord at various stages in the development of man, which affords some insight into the processes accompanying the formation of the posterior fissure. In human embryos of about six weeks the central canal is diamond-shaped on cross section; its epithelium is of nearly uniform thickness except in the dorsal part.

In the median portion of this region it is exceedingly thin, whereas on either side it presents swellings which in cross section have a knob-like appearance. In this region the epithelium is not covered by either the gray or the white substance of the cord.

In embryos of nine or ten weeks a cross section of the cord shows, according to Kölliker, the posterior columns raised into two parallel ridges. The floor of the shallow furrow embraced between them, which he says is the actual posterior fissure, is formed by the outwardly convex surface of the epithelial lining of the central canal.

Later these elevations come to lie close together, so that only a narrow slit is found between them; yet they do not coalesce. Even in the third month there is a connective-tissue partition between them. They become more and more reduced to the level of the surface of the cord, and a kind of separation takes place within, which results in splitting them off as two wedge-shaped bands, which he calls the Goll'sche Keilstränge.

No account is given of the manner in which the furrow is deepened.

Clarke ('62, p. 916) describes the formation of the posterior fissure as follows: —

"At the commencement of these changes," i. e. those which lead to the formation of the posterior fissure, "the central canal reaches the surface of the posterior gray substance. The growth of this substance is then continued, not only backward, but *outward* from the mesial line, while in the intervening angular and gradually increasing space between it and this line are developed on each side two new pyramidal columns of longitudinal fibres, which increase in depth in a corresponding proportion.

"Of these the outer one, which is much the larger, rests on the back of the cornu, over which it ultimately blends with the *outer* portion of the posterior columns previously developed.

"The inner and smaller column is in general more conspicuous and distinct in the dorsal and cervical than in the lumbar region. The opening between these additional columns constitutes the posterior median fissure, which is now occupied by blood and pia mater in connection with radiating fibres from the central epithelial layer."

Foster and Balfour ('74, p. 187) give a very different account of the formation of the fissure. In the embryo chick of seven days the central canal is divided, according to these authors, into two parallel tubes by the median coalescence of its lateral walls, thus forming a dorsal and a ventral canal. Afterwards the roof of the dorsal canal is

partially absorbed, thus converting the canal into a wedge-shaped fissure, whose mouth, however, is closed by a triangular clump of elongated cells. Below this mass of cells the fissure is open. In the lumbar and sacral regions the two canals still communicate.

Thus the posterior fissure is claimed to be part of the lumen of the original neural canal.

Lubinoff ('74, Pl. VII.) figures the same elevations of the posterior columns that Kölliker has described, but does not deal with the development of the fissure.

Waldeyer ('76, p. 23) says that the canal closes dorsally by an ingrowth of cells. Afterwards the median part of the posterior columns grows towards the central canal on each side of the median plane. These always grow from the already formed parts of the posterior columns.

After reproducing the substance of his earlier account of the formation of the fissure in man, Kölliker ('79, p. 597) says that in the embryo rabbit the posterior columns, after reaching, on the seventeenth day, the posterior median line, grow inwards toward the central canal, apparently without the formation of any Keilstränge.

In the case of the sheep, Loewe ('80, p. 75) finds the first trace of the posterior fissure in embryos of 1.5 cm. The Goll'sche Keilstränge also appear at this stage. Between the pyramids there are fibres corresponding to the anterior horn fibres. They later develop into the posterior horn fibres.

In embryos of 2 cm. the Keilstränge occur as two lateral formations, rounded ventrally, and lying close to one another. They are somewhat divergent behind, thus embracing an opening, the posterior median fissure. The Keilstränge are formed very late, but develop fast in comparison with the other columns. He does not state in what manner this fissure becomes deepened.

Balfour ('81, p. 344) confesses that he has "some doubts as to the complete accuracy" of the conclusions to which Foster and he had previously arrived ('74, p. 187). He thinks it probable that the dorsal fissure is a direct result of the atrophy of the dorsal part of the central canal. Dorsally the walls of the canal coalesce, and the fusion gradually proceeds ventralwards, so as to reduce the canal to a minute tube. The epithelial wall formed by this fusion on the dorsal side of the canal is gradually absorbed.

"The epithelium of the central canal at the period when its atrophy commences is not covered dorsally either by gray or white matter, so that with the gradual reduction of the dorsal part of the canal and the

absorption of the epithelial wall, formed by the fusion of its two sides, a fissure between the two halves of the spinal cord becomes formed." This is the posterior fissure. During its formation the white matter of the dorsal columns becomes prolonged so as to line its walls.

Material.

The present investigations were made exclusively on embryos of the pig.

When sufficiently small these were placed for a few hours in picro-sulphuric acid,* and then hardened in alcohol. In the latter process stronger grades were gradually substituted for the weaker, beginning with 70 per cent.

To render embryos in which ossification had begun suitable for sectioning, they were either placed *in toto* in picro-nitric acid long enough to remove the salts of lime and then hardened, as in the case of younger embryos, or the desired portions were cut from the embryos and treated in the same manner.

Most of the specimens thus prepared were stained in a neutral aqueous solution of carmine before cutting; some, however, were stained in picro-carmine; the results were less satisfactory with the latter method.

The measurements were taken from the tip of the nose to the root of the tail following the curvature of the back.†

Observations.

In embryos 43 mm. long cross sections through the posterior part of the lumbar enlargement show that the dorsal wall of the central canal is still composed exclusively of epithelial cells.

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* Kleinenberg's preparation, viz.: Sat. aq. sol. picric acid, 100 parts; conc. sulphuric acid, 2 parts; diluted with three times its volume of distilled water.

† The following table will enable the reader more easily to compare the stages I have employed with those used by other observers, who have usually given the length as measured from the mid-brain to the most distant point of the embryo in its normal curved position.

Measured along the curvature.	Measured in a straight line.
43 mm.	28 mm.
54 "	29 "
65 "	35 "
100 "	65 "
125 "	78 "

The cuticula interna (Pl. III. fig. 1, *i*) presents a marked thickening along the dorsal edge of the still slit-like central canal.

There is in the dorsal wall of the canal in the median plane a tract which is destitute of nuclei; it is composed of fibres differentiated from the epithelial cells the nuclei of which lie at their peripheral ends; the central ends of the fibres abut upon the cuticula interna. These nuclei are granular and oval, the longer axis having a dorso-ventral direction. It seems probable from the arrangement of the fibres and nuclei that the latter remain practically fixed, while the cells to which they belong — inasmuch as they are attached to the cuticula interna, which retreats with the restriction of the canal — are drawn out into fibres, which later are metamorphosed into the posterior horn fibres. More and more of the cells from the lateral epithelial walls of the canal are drawn in towards the median plane as the closure proceeds.

The posterior white columns (Pl. III. fig. 1, *h*) have not yet reached the dorsal median line, but as seen in cross sections appear to gradually thin out as they approach it.

In the dorsal region the nuclei are somewhat more elongated, but their extremities are still rounded. The lumen of the canal is of about the same shape as in the cervical region, but it is somewhat less restricted (Pl. I. fig. 2).

In embryos 54 mm. in length cross sections through the cervical region (Pl. III. fig. 2) show that the white columns have approached much nearer the median plane; there is, however, between their proximal edges and this plane a space which is filled with a reticulum that is directly continuous with the gray substance. In the deeper parts of this tract there are many nuclei, but as one approaches the surface of the cord they gradually disappear. The white columns have already begun to grow towards the central canal, there forming two inwardly projecting horns, afterwards known as the Burdach'sche Keilstränge. In the median plane there is a kind of partition formed of fibres which are derived from the epithelial cells of the primitive canal; it extends from the dorsal edge of the canal to the surface of the cord.

Pl. III. fig. 3, shows a section through the lumbar region of the same embryo. Here the posterior columns have not yet begun to develop towards the central canal. The restriction of the canal has not proceeded so far as in the cervical and dorsal regions. Compare Pl. I. figs. 7 and 8.

In the sacral region (Pl. I. fig. 8) the epithelium of the central canal still extends to the surface of the cord.

The degree to which the posterior columns approximate each other

varies considerably both in the different regions of the same embryo and in the corresponding regions of different stages, as may be seen from the outlines (Pls. I. and II.); in some sections the space between them is so narrow as to leave room for only one or two fibres. A few nuclei are constantly found in the fibrous substance occupying this intercolumnar space while there are as yet none in the columns themselves.

Already at this stage there are indications of fibres running across the median plane, just ventral to the posterior columns, and serving to connect the posterior horns. These fibres are probably connective tissue, and not nervous elements.

In Pl. III. fig. 4, from the lumbar enlargement of the same embryo, is shown the relation the nuclei bear to the posterior horn fibres. The latter expand into a brushlike enlargement, one end of which is merged in the cuticula interna, while the corresponding nuclei are situated at a considerable distance from the cuticula.

Cross sections through the posterior lumbar region of embryos 60 mm. long (Pl. III. fig. 5) show a pair of cords (G), composed of a coarse network of fibres, occupying the space between the posterior columns. They are more firmly connected with the pia mater than is the white substance of the columns, as is proved by the fact that they maintain their connection with the pia, while the white substance is separated from it by the shrinkage due to the hardening fluids. These cords contain nuclei which have a granular appearance. I am inclined to consider this apparently granular condition the result of the nuclear metamorphosis which immediately precedes cell division, and consequently that the cells composing this tissue are still undergoing rapid proliferation. The columns diverge at their dorsal edges, embracing between them a triangular space filled with a network of more delicate fibres than those of the cords themselves. Undoubtedly these cords are merely the result of a further modification of the cells embraced between the columns in the preceding stages. The position of the nuclei indicates at least that they are genetically connected with the nervous cord rather than its pia-mater sheath.

The connection between the posterior horns is very plainly marked at this stage, the round homogeneous nuclei of the gray substance being in striking contrast to the oblong reticulated nuclei of the epithelium. In this stage nuclei are also found in the posterior columns; they make their appearance first near the deeper margin of the white substance, as may be seen in Pl. III. fig. 5.

Sections from the lateral columns (Pl. III. fig. 7) indicate clearly,

I believe, that what Kölliker ('79, p. 596) has ventured to suggest as *possible* is in reality the only rational explanation of the presence and position of these nuclei. They exist, as Kölliker has said, independently of the blood-vessels. It is also quite certain, from the position they occupy when first seen, that they must have been derived from the gray matter of the cord.

The columns have by this time (Pl. III. fig. 6) become thickened along their median edges, and begun to grow ventralwards along the outer margins of the tract occupied by the horn fibres.

The posterior columns are already divided into numerous fasciculi of various shapes by connective-tissue septula, which have in general a radial direction extending from the gray substance toward the pia mater.

When embryos have reached the length of 85 mm. the Burdach'sche Keilstränge (Pl. III. fig. 11, B) extend in the cervical region about half-way from the periphery to the central canal, and have pressed together closely the distal ends of the above-described cords, which now may properly be called the Goll'sche Keilstränge. The latter are separated from each other only by the partition of horn fibres before mentioned.

At their distal edges Goll's Keilstränge are distinct from Burdach's, being separated from them by processes of connective tissue which are continuous with the pia mater; at their proximal margins, however, they can only be distinguished from them by the different directions which the fasciculi take in the two cases; in the former, their ventral edges trend towards the median plane, whereas the corresponding edges of the latter have a direction away from this plane. They cannot be distinguished by their histological structure; neither by the size of the nerve fibres nor by the size and arrangement of the fasciculi. Both are composed of fine longitudinal fibres arranged in fasciculi which are separated from each other by connective tissue.

The nuclei have nearly all disappeared from the Goll'sche Keilstränge, the few that remain presenting a more ragged appearance than in the previous stages.

The further development of this region may be summarized in a few words. It results from the apparent infolding of the posterior columns that the white substance approaches nearer and nearer to the canal, pushing before it the transverse connective-tissue fibres, which thus come to make a broad ventrally convex curve, the ends of which (Pl. III. fig. 11) sweep up along the lateral margins of Burdach's Keilstränge.

The growth of the Burdach'sche Keilstränge towards the central canal does not take place with uniform rapidity in all parts of the cord, neither is there an uninterrupted gradation in the advancement of this process from one end of the cord to the other; they grow much more rapidly in the cervical and lumbar enlargements than elsewhere.

There seems to be no causal connection between the closure of the canal and the development of the posterior fissure, since the dorso-ventral diameter of the canal is very frequently reduced to nearly its minimum length before the white substance of the posterior columns, on the morphological condition of which the presence or absence of the fissure depends, begins to grow ventralwards.

In embryos measuring 125 mm. and upwards the canal is so reduced as to appear in cross sections like a round or slightly oval opening, but in the dorsal and sacral regions of many of these embryos there is scarcely a trace of an ingrowth on the part of the posterior columns. (Compare Pl. II. figs. 30, 32.) Later stages in the development are shown in Pl. II. figs. 33–36.

Until the embryos have grown to the length of 186 mm., the latest stage I have sectioned, the posterior fissure remains closed, i. e. the walls of the Goll'sche Keilstränge remain close together, being only separated by the horn fibres which completely fill the space between them. In the dorsal and sacral regions, even at this advanced age, the Keilstränge have made very little progress towards the canal.

In no stage is there any evidence of a direct median coalescence of the facing walls of the canal. If such fusion actually occurred, one should find, in some sections at least, a keel-like blade of cuticula projecting dorsally from the cuticula interna which lines the roof of the canal at all stages; or, in the event that the fusion were to occur more promptly near the centre of the canal than along its dorsal edge, there might even be a vertical blade of the cuticular substance entirely separated from the cuticula lining the roof of the persistent portion of the canal. But such structures are never to be observed, the cuticular lining of the roof of the canal always presenting an even curved outline, not only for the face which looks inward toward the lumen of the canal, but also for that which is directed away from it.

It is therefore evident that the lumen of the canal is restricted from the dorsal towards the ventral side by a gradual and continuous process, which causes a shifting of the epithelial cells and makes their long axes pass from a direction perpendicular to the median plane into one more nearly parallel with it, as the cells are successively brought into the region of coalescence.

The posterior fissure, so called, is carried ventrally with the Burdach'sche Keilsträngc, either contemporaneously with this restriction of the canal, though more slowly, or else not until after the restriction is far advanced.

REDUCTION OF THE CENTRAL CANAL.

Literature.

According to most authors the central canal of the spinal cord in the adult is formed from the ventral portion of the primitive canal. Thus Kölliker ('61, p. 261) says that the primitive canal undergoes a gradual atrophy from the dorsal edge ventralwards, and that its obliteration is due to the increase in size of the posterior columns.

Balfour and Foster ('74, p. 186) claim that in the chick the canal is divided into two portions, a dorsal and a ventral, by the median coalescence of its walls, and that the ventral becomes the permanent canal.

Waldeyer ('76, p. 23) takes the same view as Kölliker.

The latter still ('79, p. 590) maintains the same opinion as in his previous writings on this topic.

According to Loewe ('80, p. 119), however, the primitive canal suffers a reduction of its caliber both dorsally and ventrally. He bases his conclusion on the fact that the epithelial cells at the anterior (ventral) edge of the canal have an arrangement of nuclei and fibres similar to that of the cells at the posterior edge; i. e. the nuclei are situated at the peripheral ends of the cells, while the central ends have a clear fibrous appearance. He says that the fibrous ends of these epithelial cells coalesce just as they do on the dorsal side, and that they are in a similar way transformed into horn fibres.

Balfour ('81, p. 345) says that the walls of the canal coalesce dorsally, and that the coalescence then proceeds ventralwards, so that finally it reduces the canal to a minute tube formed of the ventral part of the original canal.

Observations.

It can be shown from a series of measurements of the absolute length of the epithelium forming the floor of the canal, together with measurements of the distance from the lumen of the canal to the bottom of the anterior fissure, that there is neither a gradual change in the former nor a corresponding increase of the latter, as would naturally be expected if the canal closes along the ventral as well as the dorsal

side. There is, it is true, a variation in the thickness of the epithelium and in the other measurements, but it shows no gradation correlated to the gradual increase in the size of the cord. (Compare table, p. 108.)

Moreover, the epithelium in this region shows no marked histological change accompanying the growth of the cord. None of the changes which accompany the atrophy of the canal in its dorsal portion are visible here. There is neither a thickening of the cuticula interna on the ventral side of the canal corresponding to that which is constant along the apex of the dorsal side, nor is there a partition of horn fibres marking the line of fusion of the side walls of the canal, such as exists on the dorsal side of the canal.

In general, the canal has a broadly rounded floor, which contrasts strongly with the often fissure-like condition of the roof. This we should not expect to find if the canal closed from its ventral as well as from its dorsal side.

RÉSUMÉ.

The posterior columns after covering the posterior segment of the cord develop inwards towards the central canal as two horns known as Burdach's Keilstränge. They do not abut upon one another at first, but embrace between their approximated edges two masses of cells, one on either side of the median plane, which later become metamorphosed into Goll's Keilstränge. The latter are therefore developed independently of the posterior columns, and are not split off from them as Kölliker ('61, p. 262) has maintained. As the posterior horns develop towards the central canal, they carry between them the posterior fissure, which is filled with the horn fibres derived from the epithelial cells of the central canal.

There is neither a median coalescence of the side walls of the canal, as Balfour and Foster ('74, p. 186) describe in the chick, nor is the reduction of the canal brought about by the growth of the posterior columns, as Kolliker states ('61, p. 261); but the diminution in the caliber of the canal and the development of Burdach's Keilstränge — the latter process being accompanied by the development of the posterior fissure — are entirely independent phenomena.

The nuclei of the white substance originate independently of the blood-vessels. They appear first in those portions of the white substance lying nearest the gray matter, and are undoubtedly derived from the latter.

There is no atrophy of the ventral part of the primitive canal, as Loewe ('80, p. 119) has maintained, but the central canal of the adult represents the ventral portion of the primitive canal.

TABLE OF MEASUREMENTS.

L.	Cervical.			Dorsal.			Lumbar.			Sacral.		
	A.	B.	C.	A.	B.	C.	A.	B.	C.	A.	B.	C.
38	.222	.083	.384	.180	....	....	.194	.069	.360	.152	,055	.361
43	*.236	.111	.470	.111	.041	.369	.125	.055	.462	.125	.055	.462
47	.166	.069	.415	.125	.055	.462	.125	.069	.552	.139	.055	.396
51	*.222	.097	.437	.180	.069	.308	†.139	.055	.396	.180	.069	.308
54	*.166	.069	.415	.166	.069	.415	.111	.069	.621	.166	.069	.415
60	.139	.055	.410	.166	.069	.415	.180	.083	.406	.180	.069	.308
65	*.208	.097	.467	.236	.097	.411	.208	.083	.399	.222	.083	.384
72	.208	.097	.467	.222	.083	.384	.194	.069	.360	.264	.111	.420
80	*....	.111	....	.222	.097	.437	.222	.083	.384	.194	.069	.360
85	*.180	.083	.406	.166	.069	.415	.166	.083	.500	.152	.069	.454
93	.180	.083	.406	.166	.083	.500	†.139	.055	.396	.097	.041	.423
97	*.208	.097	.467	.166	.069	.415	†.166	.083	.500	.139	.055	.396
100	*.166	.069	.415	.166	.083	.500	.166	.083	.500	.152	.069	.454
110	*.180	.097	.524	.180	.083	.406	.166	.069	.415	.125	.055	.462
115	*.166	.083	.500	.152	.069	.454	.166	.069	.415	.111	.041	.369
125	*.150	.083	.505	.152	.069	.454	.166	.069	.415	†.166	.069	.415
135	....	....	....	.180	.083	.406	.180	.069	.308	.152	.055	.361
145	*.208	.097	.466	.180	.083	.406	†.194	.069	.360	.139	.069	.496
155	....	....	....	.180	.069	.308	.166	.069	.415	†.166	.069	.415
165	*.166	.083	.500	.139	.083	.596	.152	.069	.454	.139	.083	.596
175	.180	.083	.406	.166	.083	.500	.152	.069	.454	.111	.048	.432
185	....	....	....	.152	.069	.454	†.166	.069	.415	.166	.055	.331

EXPLANATION OF TABLE.

The foregoing summary presents in a tabulated form the results of a series of measurements of, first (column A), the distance from the anterior (ventral) edge of the lumen of the central canal to the bottom of the anterior fissure (Pl. I. fig. 1, α to γ), and, secondly (column B), the length of the epithelial cells at the

anterior edge of the canal (Pl. I. fig. 1, α to β), in the cervical, dorsal, lumbar, and sacral regions of embryos from 38 to 185 mm. in length.

In the column marked L is given the length of the embryo in millimeters,* and in C, the computed ratio of measurements in column B to those in column A.

Those measurements which are marked with a star are from the cervical enlargement, and those marked with a dagger are from the lumbar enlargement.

EXPLANATION OF PLATES.

The following letters have the same signification wherever used: —

a. Anterior white columns.
B. Burdach'sche Keilstränge.
b. Region of modified epithelium nearly free from nuclei.
c. Central canal.
d. Anterior commissure.
e. Epithelium of the central canal.
f. Posterior horn fibres.
G. Goll'sche Keilstränge.
g. Internuclear connective tissue.
h. Posterior horns.
i. Thickening of cuticula interna.
l. Lateral columns.
n. Nuclei in the white substance.
r. Reticulum between the dorsal edges of Goll's Keilstränge.
x. Transverse fibres connecting the posterior horns.

Plates I. and II.

[Reproduced from ink drawings by Heliotype process.]

Outlines of a series of cross sections through the cervical, dorsal, lumbar, and sacral regions of embryos from 43 to 165 mm. in length; magnified 33 diameters. All the sections in the upper row are from the cervical region; those of the second row are from the dorsal; the third, from the lumbar; and the fourth, or bottom row, from the sacral region. The corresponding sections from successive stages are not from exactly corresponding regions, which will explain the difference in size and proportions.

Figs.	1–4	from	an embryo	43	mm. in length.
"	5–8	"	"	54	" "
"	9–12	"	"	65	" "
"	13–16	"	"	85	" "
"	17–20	"	"	97	" "
"	21–24	"	"	100	" "
"	25–28	"	"	125	" "
"	29–32	"	"	145	" "
"	33–36	"	"	165	" "

Plate III.

[Reproduced by the Albertype process from pencil drawings.]

Fig. 1. A transverse section through the posterior part of the lumbar enlargement of an embryo 43 mm. in length, magnified 410 diameters. e', cells formerly a part of the epithelium of the central canal.

Fig. 2. A transverse section through the cervical region of an embryo 54 mm.

* Compare page 101.

in length, magnified 145 diameters. G′, intercolumnar mass of gray substance, the beginning of Goll's Keilstränge. B′, thickening of the posterior columns, the beginning of Burdach's Keilstränge.

Fig. 3. A cross section through the lumbar region of the same embryo, magnified 410 diameters.

Fig. 4. A cross section through the lumbar enlargement of the same embryo, magnified 410 diameters.

Fig. 5. A cross section through the lumbar enlargement of an embryo 60 mm. in length, magnified 410 diameters.

Fig. 6. A cross section through the lumbar enlargement of an embryo 100 mm. in length, magnified 145 diameters.

Fig. 7. A cross section through the lateral column and adjacent gray substance of an embryo 60 mm. in length, magnified 410 diameters.

Fig. 8. A cross section through the lumbar region of an embryo 97 mm. in length, magnified 145 diameters.

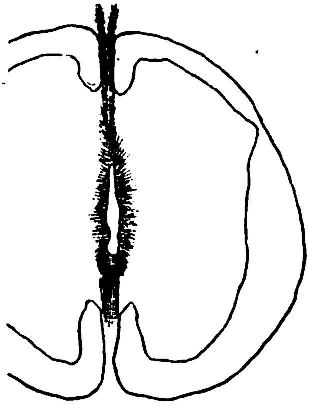
Fig. 9. A cross section through the cervical region of an embryo 145 mm. in length, magnified 145 diameters.

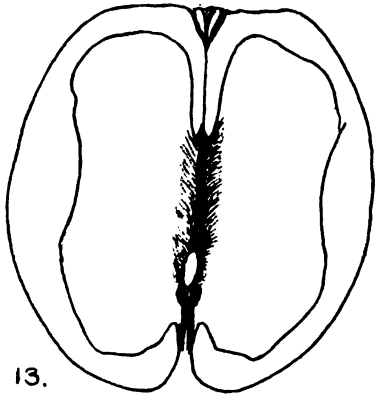
Fig. 10. A cross section from the lumbar region of an embryo 75 mm. in length, showing the elongation of the epithelial cells in the dorsal wall of the canal into fibres, magnified 470 diameters.

Fig. 11. A cross section through the cervical region of an embryo 85 mm. in length, magnified 410 diameters.

Fig. 12. A cross section through the dorsal region of an embryo 47 mm. in length, magnified 410 diameters, showing the disposition of the fibres and nuclei at the *anterior* wall of the central canal.

Cambridge, June, 1883.





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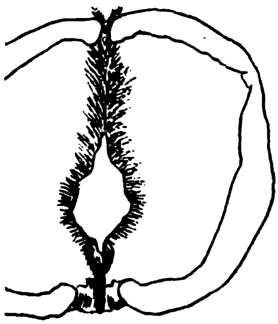

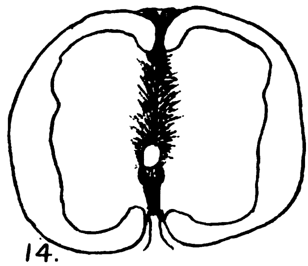

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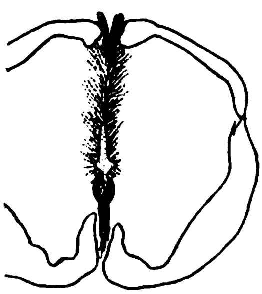

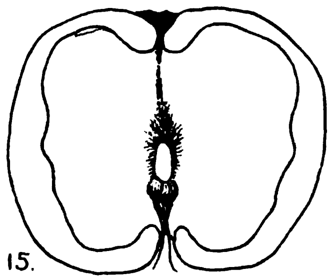

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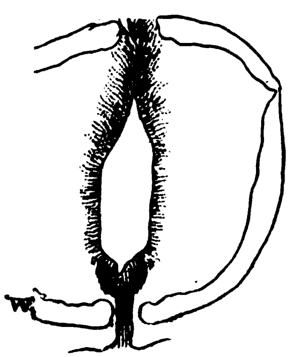

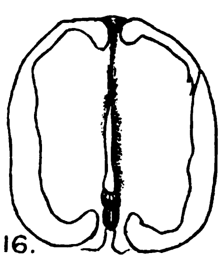

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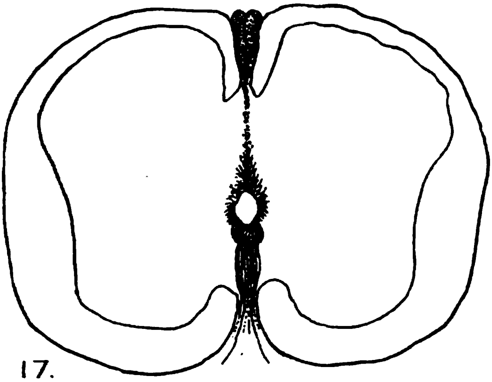

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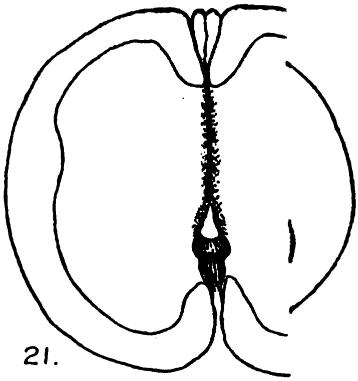

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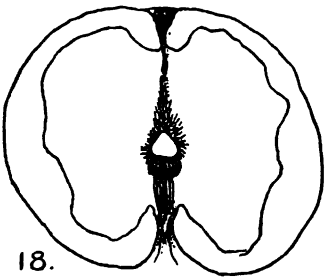

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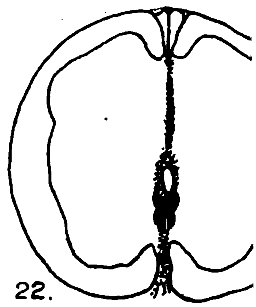

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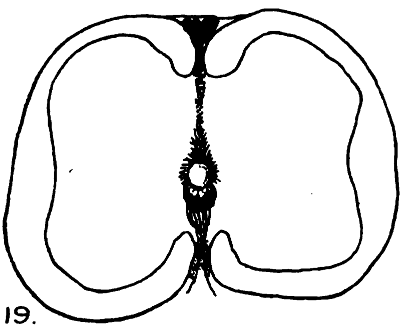

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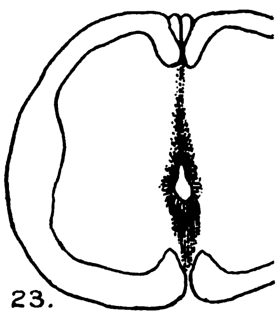

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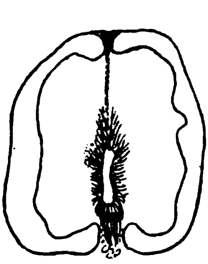

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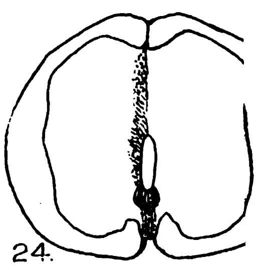

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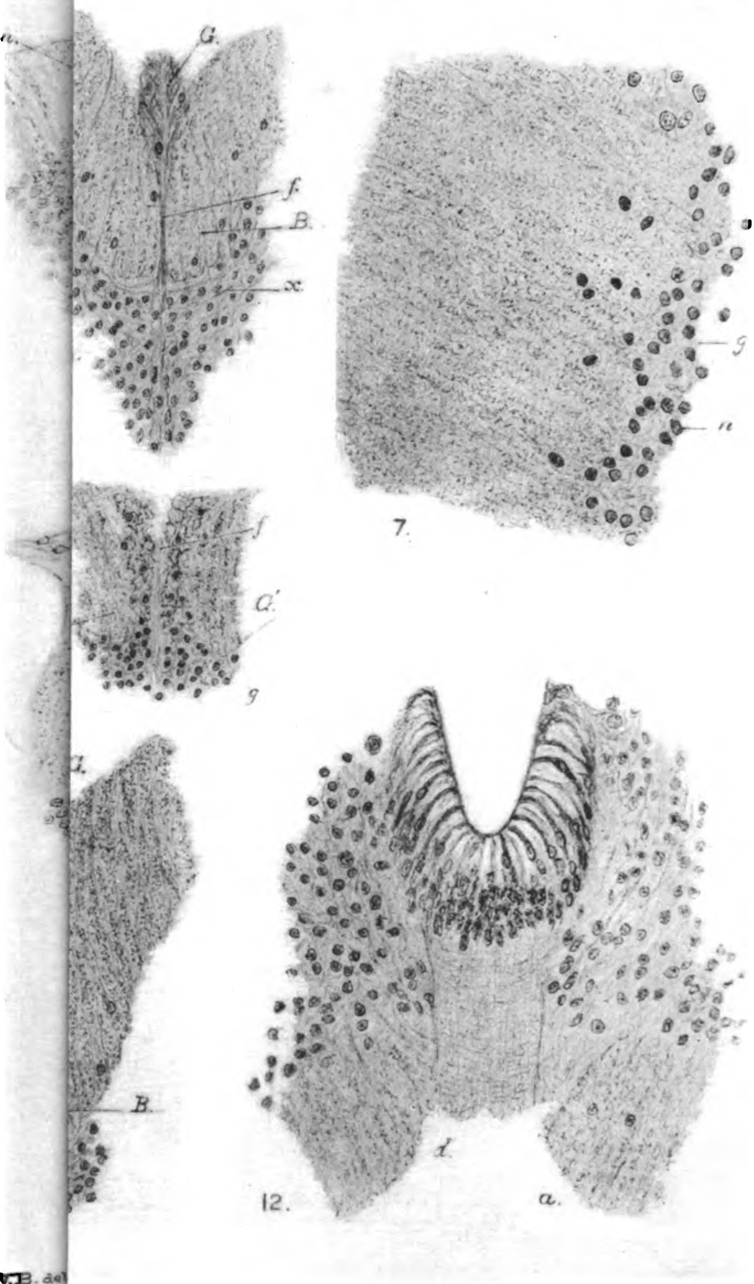
BARNES, *Posterior Fissure.* Pl. III.



III.

CONTRIBUTIONS FROM THE ZOÖLOGICAL LABORATORY OF THE MUSEUM OF COMPARATIVE ZOÖLOGY AT HARVARD COLLEGE.

No. II. — THE RELATION OF THE EXTERNAL MEATUS, TYMPANUM, AND EUSTACHIAN TUBE TO THE FIRST VISCERAL CLEFT.*

By Albert H. Tuttle, Boston.

Presented June 13, 1883, by Alexander Agassiz.

The recent revival of Von Baer's views† upon the development of the accessory parts of the ear in mammals again puts the question of their possible connection with the first visceral cleft in an unsettled condition. Such being the case, a reinvestigation of the problem seems desirable. It has been the aim of the author in the present paper to go over the ground in the case of the pig, and, with the aid of a more continuous series of embryos and improved methods of investigation, to ascertain in how far this recently revived theory is worthy of acceptation.

Historical Synopsis.

In 1825 Rathke ('25, col. 747–749)‡ discovered, in the case of an embryo pig half an inch in length, that on either side of the neck immediately behind the head there were four gashes. These were successively smaller from before backwards, and all had a transverse or dorso-ventral direction. It was shown by dissection that they extended through the walls of the throat into the pharyngeal cavity. He accordingly called them "Schlundspalten" (throat clefts). At the same time

* Prepared in the Embryological Laboratory under Dr. E. L. Mark.

† Especially by Hunt and Urbantschitsch.

‡ At page 130 will be found a list of the papers cited, the names of authors being arranged alphabetically, the papers of each author chronologically. In the body of the paper the number immediately following the name of the cited author is an abbreviation for the date of the article referred to, and will enable the reader to turn at once to the full title of the paper.

he insisted upon their homology with the gill slits, especially of sharks, and therefore also designated them "Kiemenspalten" (branchial clefts). An embryonic horse two thirds of an inch long, which had lain some time in spirit, was taken for comparison. Although the external wall of the throat was smooth, the inner surface showed on either side four moderately deep furrows, having the same general form and position as the clefts in the case of the pig. Rathke thereupon came to the conclusion, that the embryos of mammals generally are provided with gills, and that the clefts are gradually closed by a fusion of their walls, which progresses from without inwards. This was, in substance, the important investigation which Von Baer afterwards alluded to as "Rathke's brilliant discovery of gill clefts."

Huschke ('26, col. 620) communicated to the assembly of German naturalists in September, 1825, his studies on the development of the frog and other amphibia. In the frog the gill apparatus becomes the middle ear, in that the inner opening of the first cleft becomes converted into the Eustachian tube. Huschke ventured to go farther, and to predict that in birds and mammals the first of the clefts recently discovered by Rathke becomes converted into the external meatus.

In the following year Huschke ('27, col. 401) extended his observations to the chick, where he found that between the two arches (mandibular and hyoid) there was a large hole which opened only a little farther back than the first gill cleft, and also at first led into the mouth cavity. It was no longer a gill opening, but external meatus, whereby it was in his opinion still better (than in frogs) established that this opening (i. e. as well as the Eustachian tube) possesses in the branchial fissure its first outline.

Rathke ('28, col. 80–85) soon after reported that he had not seen this hole, and he expresses a doubt as to its being the external meatus, even if it does exist.

Huschke subsequently ('28, col. 162) reaffirmed his interpretation of this opening in an article accompanied with illustrations. From the fourth to the fifth day a fine hair could be passed *without resistance* through this opening and the Eustachian tube into the throat and mouth, from which he inferred that the tympanic membrane was not yet formed. Von Baer ('28, p. 77), describing the chick of the fourth day of incubation, simply says that he observed a deep depression in the bottom of the pharynx pointing toward the ear, and that it was probably the beginning of the Eustachian tube. Early in the fifth day the first gill slit becomes unrecognizable (p. 83). The ear is indicated by a round elevated ridge, but the depression which it surrounds

remains very inconspicuous during the fifth day. Although the ear appears to have at this time an opening inward by means of the Eustachian tube, the external orifice is ordinarily formed on the following (sixth) day, so that it makes its appearance when the gill slits are closed. Still it was sometimes seen when one or the other of the clefts remained (p. 87). In the same year he (Von Baer, '28[a], p. 147) criticised Huschke's view in the following words: "The circumstance that the most anterior gill cleft is early reduced in length, and that its upper persists longer than its lower part, appears to have induced Huschke to regard it as the opening of the ear. So much is certain: the outer orifice of the ear can have nothing in common with the gill apparatus, since the ear belongs to the superior half of the animal (i. e. the Rückenplatte), and not to the inferior half (Bauchplatte), to which the gills belong." Von Baer admits, however, that the Eustachian tube is a prolongation of the superior half of the body into the inferior part.

In answer to this criticism of his theory of the transformation of the first cleft, Huschke ('32, pp. 40, 41) declared that Von Baer was in error in saying that the entire ear belongs to the superior half of the body; only the labyrinth is formed from it, the accessory parts being formed by the metamorphosis of the superior part of the first cleft. Huschke supported his position by renewed investigations, and by arguments based upon malformations observed in certain cyclopean monsters. The first pair of clefts, at first widely open, becomes, he says, progressively closed from the ventral median line backwards and upwards, and thus become widely separated, until at last only the outer or upper angle of each fissure is left as a hole, — the *meatus auditorius externus*, — which leads directly into the throat by means of the Eustachian tube without any tympanic enlargement.

Valentin ('35, p. 211) concludes from his own observations that it is not to be doubted that the Eustachian tube is the remnant of the inner end of the first visceral cleft, but is uncertain whether the tympanic cavity and the external meatus are "formed out of the whole external part of the cleft." His objection is based on the fact, that the first indication of the external opening of the ear does not lie in a line with the fused lips of the cleft, but "apparently above it in the substance of the posterior boundary of the first visceral arch."

Reichert's ('37, pp. 149–155) studies were made principally on the pig. He was the first to follow the successive changes of the hyomandibular cleft through a numerous series of embryos.* In many

* It was Reichert, also, who introduced the terms "Visceralbogen" and "Visceralspalten."

points concerning the external features of the cleft I have been able to confirm his conclusions. Soon after the confluence of the arches on the ventral side, says Reichert, there appear on the margins of the arches which bound the remnant of the first cleft elevations, the apices of which are directed toward each other; each of these elevations lies between two slight depressions. The cleft is thereby made to appear broader at two places (the ends), and narrow in the middle. In the further metamorphosis of the parts there are two points of importance: the changes of these elevations and depressions, and the actual and apparent migration of the external opening of the cleft. In stages where the second and third clefts are already closed, it can be ascertained by manipulation that the tissue which seals up the first cleft lies, as Rathke claimed, nearer the external than the internal opening of the cleft. Of the two broadened ends of the cleft, the lower (ventral) becomes the deeper and more important.

As seen from the side, the arches present, beside the two elevations mentioned, other smaller elevations and depressions, which together with the former surround the visceral opening like two walls. While the lower division of the cleft is continually becoming more evidently metamorphosed into the external meatus, the posterior wall, which is really an outgrowth of the second visceral process, gradually becomes higher, and while its main elevation forms, as it were, the root or stem of the external ear, the rest of it becomes the concha. The anterior wall does not become prominent.

As regards the second point, the remnant of the cleft at first lies between the upper (dorsal) portions of the first and second visceral processes, and it continues to occupy this position in relation to the forming parts; the latter, however, are shifted backwards by the formation of the lower jaw and the tongue, and in consequence of this the plane of the fissure, which was at first nearly perpendicular to the long axis of the embryo, becomes gradually more oblique. The apparent dorsal migration of the external opening, on the other hand, is due to the formation of the facial parts, especially to a gradual broadening of the ventral portion of the embryo in the ear region.

The inner portion of the cleft is elongated into a canal by the growth of the surrounding tissue. The canal is somewhat narrowed by the encroachment of the labyrinth near the place where the fusion of the walls of the cleft first took place; the portion lying outside the constriction becomes the tympanum, the rest becomes the Eustachian tube. The latter does not diminish in size, as Valentin claimed, nor is its axis changed in direction, but remains from the beginning directed, from outwards and forwards, inwards and backwards.

While Günther ('42, pp. 32, 56) agrees with Reichert as to the division of the external portion of the cleft into two parts, he disagrees entirely as to the fate of these parts. The edges of the first cleft fuse at first in the middle, so that instead of one there are two openings, the lower (ventral) of which suffers no metamorphosis and soon disappears entirely. The upper orifice is converted, the outer parts into the external parts of the ear, the inner into the tympanum and Eustachian tube.

In his text-book Bischoff ('42, p. 410) follows in the main the conclusions reached by Reichert, but, contrary to that author as well as to Rathke, he places the partition which separates the inner from the outer part of the cleft midway between the two ends, "in the middle of the thickness of the two arches."

According to Kölliker ('61, pp. 321, 322), the first cleft is closed in the human embryo in the fifth week; not, however, in its totality, like the other clefts, but so that on both sides of the place of union — which lies near the external orifice — the outer and inner ends remain open, and are respectively nothing else than the beginning of the external meatus and of the Eustachian tube and tympanum. The region of the union represents the primitive tympanic membrane. Subsequently the inner part of the cleft increases in length, and gradually becomes wider at its hinder or outer end.

In his lectures Rathke ('61, p. 117) taught that the first cleft in frogs and many toads, as well as in turtles and saurians, is only closed near its outer end, and from the substance effecting the closure is formed the tympanic membrane; in the case of birds and mammals, however, that it is closed at about the middle of its depth, and that the outer half of the cleft becomes the external meatus, while the inner becomes the Eustachian tube and tympanum.

In 1876 Hunt presented to the International Otological Congress a paper embracing "a new account of the development of the meatus externus, drum, and Eustachian tube." The whole paper was reprinted in the following year (Hunt, '77), and the substance of so much of it as relates to the meatus externus, etc. was also embodied in a paper published by the author in the same year in the American Journal of the Medical Sciences (Hunt, '77ª).

In these papers Hunt ('77ª, p. 1) says: "At the same time Von Baer stated an opinion as to the development of the meatus and Eustachian tube that was opposed by Huschke; here also the latter was declared victor, but I believe incorrectly." Hunt maintains that the external meatus is derived, at least in part, from a furrow formed at

the boundary of the swollen root of the first branchial arch and the neighboring tissue. "The Eustachian tube," he says ('77, p. 9), "is an involution of the mucous membrane lining the pharynx; it is not in any way the remains of a branchial fissure, but lies in the tissue in which the base of the skull is forming; it grows in length as the branchial fissure closes." He states that in cross sections of the head, which incline anteriorly as they pass downward so as to cut the first arch obliquely, the Eustachian tube can be seen as a slight depression in the roof of the pharynx. In an embryo nine sixteenths of an inch long it becomes deeper, pointing upwards and outwards. In an embryo eleven sixteenths of an inch in length the Eustachian tube overlaps the inner end of the meatus. The tissue separating the meatus and Eustachian tube becomes transformed into the tympanic membrane.

About the same time the development of the accessory parts of the ear was made the object of special studies by Moldenhauer and Urbantschitsch. Moldenhauer ('76) published a preliminary account of his results in the latter part of 1876; his conclusions will be given a little further on.

The studies of Urbantschitsch ('77) were made upon the rabbit and the chick. Supporting his statements (p. 4) by well-known conditions found in longitudinal sections of batrachians, he claims that the ridge-like thickenings of epithelium which mark the boundary between the fore-gut and the oral invagination (i. e. between entoderm and ectoderm) correspond exactly in position with the subsequently developed larynx. The oro-naso-palatal sinus in birds and mammals, which is at first much less pronounced than that of the lower vertebrates, is only definitely formed when the front part of the brain has come to form an angle with the axis of the rest of the body. It is then that the branchial arches begin to form by their downgrowth the lateral boundaries of this sinus, which is converted into the definite oro-naso-palatal cavity by the ventral union of the arches. The branchial fissures, as well as the inner wall of the arches and all other parts of this cavity, are therefore lined with *ectoderm*. The usual statement that the fissures are closed by the concrescence of the separate arches is not accurate; the closure of the clefts is effected by a crescent-shaped outgrowth of the substance of the provertebra which lies opposite the dorsal end of the cleft (p. 6). This outgrowth covers, or fills up, a portion of the dorsal part of the cleft, and a similar growth from the ventral side diminishes its extent in the opposite direction. Thus the fissure is reduced to a small circumscribed opening, — a temporary communication between the oral cavity and the outside, — which, just before its complete disappearance,

is seen to have a more ventral position (p. 7). The evidence that the fissures are not closed by a direct fusion of the facing walls of the arches Urbantschitsch finds in the fact that the *width* of the cleft does not suffer any perceptible change in the different stages, whereas a reduction of its *length* is directly visible at a comparatively early stage. "Furthermore," he says, "one can easily find in successive cross sections, either that the space between two arches discloses only the apposed layers of the ectoderm, or that between these two layers there are products of the mesoderm. Where there is no union the section passes through the region of the branchial fissure; where the two apposed layers of the ectoderm are encountered, there the cross section passes through the most peripheral part of the crescentic outgrowth; and where the provertebral mass is found between the two layers of ectoderm, there we have the already completely closed branchial fissure."

While the fissures are thus closed by the advancing mesodermic encroachments, the oral sinus undergoes a differentiation into a central and lateral portions; the latter become enlarged, and communicate with the former only by narrow fissures; the lateral enlargement becomes the middle ear, and the fissure the Eustachian tube, so that in its origin the middle ear is in no way derived from the first branchial cleft, but is to be sought in the two lateral sinuses of the oro-naso-pharyngeal cavity. The tympanic membrane as seen from the outside is at first not distinguishable, inasmuch as it lies in a plane with the external surface of the rest of the embryo; from the beginning it consists of three layers, — the external layer of ectoderm, the mesoderm, and the inner or oral layer or ectoderm (p. 13).

Only occasionally is its position indicated externally by a slight depression. This depression is the beginning of the external meatus, the entrance to which is separated from the first visceral cleft by a narrow bridge of tissue. Although this at first appears to lend support to the theory of its derivation from the first cleft, it is nevertheless not so derived. The orifice is the opening to a canal (meatus) which is entirely distinct from the cleft, and forms with it an angle the opening of which is directed inward and forward. This canal is formed by the elevation of a ridge of tissue around this depression, rather than by any ingrowth of the latter.

Urbantschitsch ('78, p. 132) in a subsequent paper reaffirms his conclusions, and claims that the external meatus is formed in the embryos of mice in a like manner.

By far the most careful and systematic description of the development of the middle and external ear is that given by Moldenhauer ('77)

for the chick. His account embraces a description of the changes as observed both from the outside and from the inner side of the branchial region, and is made as definite as possible through the aid of what is really indispensable, — series of sections both transverse and frontal.

In the chick of the fourth day the first cleft is already closed except in its posterior * third. The position of the fissure is, however, still recognizable by the presence of a furrow which is least conspicuous in the region of the middle third of the fissure, which latter, moreover, is the place in which fusion first occurs and which marks the position of the future tympanic membrane. The total length of the branchial furrow is .53 mm., of which the posterior open part occupies .17 mm.

By the sixth day the furrow has increased to .83 mm., but the posterior open portion remains unchanged in length, nor is it really open at this time, since deep down a welding has closed the passage. Two pairs of elevations — *colliculi branchiales externi* — arise from the edges of the first and second arches, and surround all of the furrow except a small anterior portion. Of the superior pair the posterior elevation corresponds in position to the root of the first arch, the anterior to the posterior end of the mandibular process. These elevations are so placed that the furrow is broken into a zigzag, the most important part of which, since it corresponds to the region of first closure, is a valley, the sides of which are bounded by the upper anterior and the lower posterior elevations, and the ends of which abut against the two remaining colliculi.

On the seventh and following days the colliculi become more prominent and the corresponding valley deeper; the lower posterior elevation soon begins, however, to become flattened, while the three remaining colliculi become confluent, and thus form a sharp lip, which slightly arches over the depression from the upper and anterior sides, and thus converts the latter into an oblique passage, the entrance to which is on the side of the flattened and finally obsolete colliculus.

The *inner* surface of the first arch in the chick of the fourth day is raised into an elongated elevation, — *colliculus palato-pharyngeus*, — which, beginning near the origin of the maxillary process, extends downward across the root of the first arch perpendicularly toward the first cleft. It gradually increases in prominence from above downward, and ends with a rounded margin at the lower edge of the first

* Moldenhauer's method of designating directions is borrowed from anthropotomy, so that his "anterior" refers to the *ventral* face of the embryo, and his "posterior" to the dorsum. For the same reason the cephalic end is called "upper" or "superior"; the caudal, "lower" or "inferior."

arch. This elevation is marked off from the rest of the arch by two grooves, both of which run into the first cleft at their lower ends; but in the upper part of their course they differ. The posterior one — *sulcus tubo-tympanicus* — gradually becomes shallower till, at its upper end, it is no longer distinguishable; the anterior, — *sulcus lingualis*, — however, bends forward at its upper end, and opens to the outside at the angle between the maxillary and mandibular processes. The latter subsequently bounds the outer margin of the tongue; the former is the beginning of the Eustachian tube and the tympanic cavity.

At its upper or basal portion the margins of the colliculus are thickened into crura; the posterior — *crus superius* — retains its perpendicular direction; the anterior — *crus inferius* — bends forward nearly parallel with the maxillary process, and is the first trace of the palatine arch. The edges of the superior crura of the opposite sides of the embryo subsequently fuse, thus forming the common sinus, characteristic of birds, into which the Eustachian tubes directly open.

Cross sections of a two-day embryo chick show that none of the clefts are formed, although the entoderm is in contact with the ectoderm in the region of the first cleft, preparatory to the formation of an opening. Similar sections of 3–4-day chicks — in which all four clefts are open — exhibit the *sulci* as narrow curved hornlike fissures. The dorsal horn, — *sulcus tubo-tympanicus*, — faintly indicated in more anterior sections, becomes deeper in the more posterior, and finally opens out through the first cleft. Its extent is shown by the position of the sections of the branchial artery; owing to its arched course the latter is twice cut in cross sections; the sulcus begins near the inner section of this vessel, where its presence causes the dorsal wall of the pharynx to protrude, and it extends outward not farther than the outer section of this artery.

On the sixth day the clefts are all closed except a small posterior portion of the first. The *sulcus tubo-tympanicus* has a bend which gives its outer end a dorsal direction. In a section through the branchial furrow, which cuts through the territory of the mandibular arch rather than the hyoid, there is in a line with the sulcus a slight depression of the ectoderm; immediately in front of this there is a prominent elevation (a section of the *colliculus posterior superior*), while in front of this elevation there is a second more deeply depressed region, — the oblique valley seen in surface views, — which terminates abruptly in front at a second elevation, the section of the *anterior* superior colliculus. This deeply depressed region lies opposite the bend in the sulcus, and corresponds to the thinnest part of the wall; it marks the place of the tympanic membrane.

In corresponding sections through embryos of the ninth day the posterior colliculus, as well as the depression behind it, no longer exists; the depressed region grows gradually deeper from behind (dorsal) forward, where it is terminated by a steep wall, — the anterior colliculus. An enlargement of the blind end of the sulcus opposite this depression is the incipient tympanum.

In an embryo of the twelfth day the external depression — the *meatus externus* — has become deeper; the deeper portion of its posterior wall is differentiated into a floor, the tympanic membrane, with which the anterior wall makes a sharp angle. The tympanic membrane is only half as thick as in the nine-day stage. Since it is not the dorsal depression, lying in line of the prolongation of the sulcus, which becomes the external meatus, but rather the more ventral depression, Moldenhauer argues that the tympanic membrane has no relation whatever to the blind end of the sulcus, its mucous surface corresponding to a definite territory of the *ventral* region of the wall of the front intestine. Similar conditions are maintained for the embryo of the deer.

From the study of *frontal* sections the author concludes that the tympanic cavity lies on the inner side of the first *arch*, since in the chick of the seventh day the *lower* (posterior) wall of the primitive tympanum lies nearly in continuation with the layer of epithelium which indicates the position of the line along which the arches fused. The tympanic membrane is formed at the expense of the substance of the mandibular arch, not that of the hyoid. This conclusion is based principally on the fact that the lower (posterior) margin of the first arch *gradually* becomes thinner in the tympanic region, and that the upper edge of the hyoid arch rises *abruptly* from the region of minimum thickness.

Kölliker ('79, pp. 746–755) still holds that the tympanum and tuba are undoubtedly developed from the median part of the posterior (dorsal) section of the first branchial fissure, which, however, is not directly and without further change metamorphosed into these parts, but which grows out into a hollow process directed outward, upwards (forward), and backwards (dorsal). At the same time the external meatus, which at first is shallow, forms also a hollow process which takes exactly the opposite direction; the meatus therefore does not become deeper simply from the upgrowth of the tissue surrounding its external opening. Kölliker finds in the rabbit nothing to favor Moldenhauer's view that the mouth of the tuba and that of the first cleft do not correspond, neither is he willing to commit himself to the opinion which makes the

tympanic membrane arise exclusively from the substance of the mandibular arch.*

Observations and Conclusions.

Does the external passage of the ear arise by a transformation of the first, or hyomandibular cleft? This question may be fully answered by observing the external changes in a series of embryos. It is to these external changes that I shall first direct attention. There are three possible *a priori* answers to the question: first, the external passage may be developed exclusively from the remnant of the cleft, simply by an outgrowth of its walls; secondly, it may arise quite independently of the cleft, by means of a new invagination and subsequent changes; or, finally, it may owe its origin in part to a transformation of the cleft, and in part to other and subsidiary changes of parts not belonging to the walls of the cleft proper.

The smallest embryo I have studied in this connection is 6 mm. long;† its form is much more simple than that of any of the later stages. The visceral arches are straight, finger-like processes, without elevations or depressions. The clefts are also straight and deep, with perfectly smooth walls; in the profile view of the embryo they extend dorsally for nearly half the breadth of the neck (Fig. 1). In this embryo only the mandibular and hyoid arches have become well defined. The otic vesicle is still traceable by an external depression due to a sinking in of its thin outer wall during the process of hardening.

In the growth of an embryo from the 6 mm. to the 8 mm. stage (Fig. 2), a considerable alteration takes place in the appearance of the head and neck. The different regions of the brain have become well marked externally; the third visceral arch is sharply defined; the mandibular and hyoid arches are swollen at their roots. The furrow described by Hunt as lying above the root of the mandible has become perceptible (Fig. 2, *d H*). The mandibular and hyoid arches have exchanged their finger-like appearance for somewhat club-shaped forms. The appearance of the first cleft has also become altered; formerly

* Unless I have myself misunderstood the figures and meaning of Moldenhauer, Kölliker is in error when he makes the latter responsible for the view that the external meatus is derived from the *most posterior* (dorsal) part of the cleft. I understand Moldenhauer to say that it is not the dorsal depression corresponding to the last closed part of the cleft, but a more ventral region of the cleft, which marks the position of the future meatus and its floor, — the tympanic membrane.

† Measurements were made in a straight line from the elevation of the mid-brain to the most distant point of the embryo as it lay in its natural position.

straight, it is now bent near the middle by an elevation formed on the anterior margin of the hyoid arch (Fig. 2, *p e*), which projects over the cleft. This elevation overlaps a depressed portion of the mandibular arch, and plays an important part in the development of the auricle of the ear.

In an embryo 9 mm. long (Fig. 3) the cleft has become more bent by the forward growth of the elevation of the hyoid arch, and the deepening of the corresponding depression of the mandibular arch. The furrow of Hunt has become limited to a small triangular depression, the ventrally directed apex — the part corresponding to the dorsal end of the cleft — being the deepest. At this stage the depression is quite conspicuous, since the roots of the hyoid and mandibular arches, which form its ventral walls, are much swollen. The elevation on the hyoid (Fig. 3, *p e*) has become more prominent, and has thus affected the shape of the first arch, the mandibular branch of which, as seen in profile, has taken an almost rectangular outline.

With embryos 10 mm. long (Fig. 4) the cleft is still more bent, and is sharply limited by the hyoid wall. Its anterior margin, however, is not so sharply marked, since the mandibular wall gradually slopes into the cleft. At either side of the hyoid elevation the cleft is deepest, becoming more shallow as one approaches its extremities. The elevation on the hyoid has increased considerably in size, and at either side of it is formed a secondary elevation (*s d*, *s v*). Each of these, although very slight as yet, is clearly distinguishable, and is separated from the primary elevation by a shallow depression (*d*). On the mandibular arch opposite these elevations there are others (*m d e*, *m v e*) which form the angles of that arch: they give a definite limitation to the cleft, and at the same time clearly define the rudimentary jaw. The depression of Hunt has become less pronounced because of the outward growth of the tissue forming its floor, owing to the more complete fusion of the roots of the mandibular and hyoid arches.

In embryos 11 mm. long (Fig. 5) the primary elevation of the hyoid has assumed a conical shape; it is thickened and swollen at the base, but thinned out at the apex, and is very sharply limited. The secondary elevations have become distinctly separated from the primary by the deepening of the depressions between them and the latter, and have thus become much more prominent. At either side of the primary elevation of the hyoid the cleft has the appearance of a deep hole, which is sharply bounded by the almost perpendicular walls of the hyoid and mandibular arches. The elevation at the root of the mandibular arch is still prominent, whereas the depression of Hunt is almost obliterated, at least in embryos prepared by the picro-sulphuric acid process.

A series of embryos from 11 mm. to 17 mm. long shows the gradual disappearance of the elevation at the root of the mandible and of the depression of Hunt. The primary elevation of the hyoid arch (Fig. 6) becomes more and more developed, and its growth is attended with apical attenuation. The secondary elevations become less conspicuous, and show a tendency to coalesce with the primary. The superior (dorsal) one, however, is still distinct. The mandibular wall continues to slope rather gradually into the cleft. The latter is now confined to the side of the head, and the surrounding parts show some resemblance to the permanent external ear; the apex of the primary elevation of the hyoid arch corresponds to the tip of the auricle.

In the case of an embryo 19 mm. long (Fig. 7), the walls of the *meatus* (for such we may now call it) are steep and sharply limited. The inferior (ventral) secondary elevation of the hyoid has disappeared, whereas the superior one still exists.

When the embryos have attained the length of 25 mm. (Fig. 8) the auricle has a triangular shape, thus approximating its ultimate form. The superior secondary elevation has by this time disappeared, and the whole aspect now closely resembles that of the ear of the animal at birth.

From this description it will be seen that the development of the auricle is the most salient feature of the external changes in the walls of the cleft, and is distinguishable at a much earlier epoch than has hitherto been claimed. It is to be seen first in an embryo 8 mm. long as a slight elevation of the anterior margin of the hyoid arch (Fig. 2, *p e*). This elevation gradually increases in prominence, but always preserves its primitive relation to the cleft, since it continues to point directly across the centre of the latter. In an embryo 25 mm. long the centre of the meatus is directly beneath the apex of this auricular bud (Fig. 8). Inasmuch as the centre of the cleft of an 8 mm. embryo occupies the same position in relation to the incipient auricle, it is fair to infer that the external meatus occupies the region of the centre of the cleft.

The long diameter of the slit does not increase to any great extent until the embryo is 30 mm. or 40 mm. long, although it increases rapidly in width after the embryo attains a length of 17 mm. From this it would seem that the depression described by Hunt (which lies at the dorsal extremity of the cleft, and owes its existence to the less rapid growth of the tissue at that point), instead of deepening, becomes obliterated by a thickening of the tissue which forms its floor. This thickening constitutes the wall bounding the dorsal extremity of the cleft. In other words, the inclined floor of this depression forms the

dorsal wall of the cleft, just as in many young stages the mandibular arch forms the sloping anterior wall of the cleft.

After bisecting an embryo 8 mm. long, and laying open the pharynx, the cavity of the first cleft may be viewed from the inside. It will be found to be a deep blind pocket extending dorsally and outwards, the opening to which is long and narrow, although somewhat wider near the centre. The inner openings of the other clefts also are still very conspicuous.

In an embryo 11 mm. in length the opening of the first cleft has become more diamond-shaped, and is sharply defined by a ridge which forms its dorsal and posterior margins. The remaining clefts, having become entirely closed, are now only recognizable as shallow furrows.

When the embryo has grown to 16 mm. in length these furrows have become almost obliterated. The ridge which forms the posterior and dorsal boundary of the first cleft is more prominent. By carefully reflecting it one may observe a bridge of tissue, the primitive tympanic membrane, through which a certain amount of light penetrates. A hair inserted from the outside through the middle of the floor of the external portion of the cleft will pass through this membrane at a point near its centre. From this it is evident that the external depression must lie directly opposite the internal part of the cleft, and that therefore the former is *not* a secondary depression at one side (dorsal) of the external part of the cleft, as claimed by Urbantschitsch.

An embryo 18 mm. long shows that the ridge still exists, and that it serves to define the pharyngeal opening of the first cleft; there remains, however, no trace of the other clefts.

In order to study the shape of the internal part of the first cleft, as well as the changes which it undergoes and its relation to the external portion of the cleft, it is necessary to employ a series of frontal and cross sections through this region at various stages of development. For this purpose embryos were killed in picro-sulphuric acid, and hardened in alcohol. They were stained *in toto* in Grenacher's alcohol-borax carmine. Several other methods of hardening and staining which I employed gave much less satisfactory results.

Sagittal sections through the head of an embryo 6 mm. long show that the walls which bound the first cleft in front and behind have already come in contact along a line running nearly parallel with the surface of the neck, but much nearer the superficial than the deep, or

pharyngeal, end of the fissure. This line of contact is coextensive with the cleft, so that the latter is closed throughout its whole length (Figs. 9, 10, 11),* although a complete fusion of its walls can hardly be said to have taken place at this time. The second cleft has not yet broken through the pharyngeal walls, so that for a short period subsequent to the formation of the first cleft there is no direct communication through the walls of the neck between the pharyngeal cavity and the outside world. The pharyngeal portion of the walls of the first cleft at this stage is composed of two layers of cells, a superficial layer of flattened epithelium, and a deep (or mucous) layer consisting of wedge-shaped or somewhat modified columnar cells. On the posterior or hyoid wall the deep layer is several cells in thickness, but on the anterior or mandibular wall this layer is usually only two, and at most not more than three, cells deep.

In cross sections through the centre of the cleft of an embryo 8 mm. long (Fig. 12), the ventral half of the external division of the cleft is separated from the internal portion by a thick partition consisting of three layers: the ectoderm lining the external portion of the cleft, the entoderm lining the internal portion of the cleft, and the mesoderm intercalated between them. The deepest portion of the external moiety of the cleft, however, which lies at its dorsal extremity and which coincides with the ventral angle of the depression of Hunt, is separated from the inner portion of the cleft by only a few cells which have been proliferated from the hyoid wall (Fig. 13). I believe this affords considerable evidence that the cleft is gradually closed from its ventral toward its dorsal edge by an upgrowth of tissue which results from a very complete fusion of the hyoid and mandibular arches.

The regions of the external portion of the cleft which play the most important part in the formation of the external meatus are indicated in the sections (Fig. 12) by *a* and *b*. They are a dorsal depression (*a*), which lies at the extremity of the cleft, and a ventral depression (*b*), which lies anterior to the primary elevation of the hyoid. From the same sections (Fig. 12) the inner portion of the cleft (*c*) is to be seen directed obliquely from the pharynx dorsally and outward. Since the inner portion of the cleft and the pharynx meet at an angle, the latter affords a well-marked indication of the extent of each. These characters are important in determining the cleft, and orienting its position in the successive stages of its metamorphosis.

Cross sections through the cleft of an embryo 12 mm. long (Fig. 14) show that the dorsal depression (*a*) has become deeper and more nar-

* Consult Explanation of Figures.

rowly limited, on account of the thickening of the walls of the head without any corresponding increase in the thickness of the floor of the depression. For the same reason the ventral depression has become deeper. This series of sections shows that an ingrowth of mesoderm has occurred even in the thinnest region of the partition, which so thickens it as to separate more than in the previous stage the inner from the outer portion of the cleft. The ingrowth is greater between the *ventral* depression and the inner portion of the cleft than it is between the dorsal depression and the latter. It reduces the inner remnant of the cleft to a narrow cavity, which, from its shape and position, we may call the inner edge of the original cleft; this persists as the tympanum and Eustachian tube, but it communicates with the pharynx proper only at its ventral end. That communication becomes the true Eustachian tube. At this stage it points directly from the pharynx to the dorsal depression (a), and the partition which separates it from the same is still very thin (Fig. 15).

By the time the fœtus has reached the length of 16 mm. the dorsal depression (Fig. 16) has become much shallower, since the bridge which separated it from the inner remnant of the cleft has become very thick. The ventral depression, on the other hand, has increased in depth. By these changes the floor of the external part of the cleft is placed in a line parallel to the internal portion of the cleft. The primitive tympanum and Eustachian tube continue to point toward the dorsal depression.

This is the stage that has misled many prominent investigators. The ventral depression, which has now become very pronounced, has been mistaken for the dorsal one, which at this time is quite inconspicuous on account of the upward growth of the tissue that forms its floor.

The length of the inner portion of the cleft, as Reichert first pointed out, has not suffered any perceptible increase; but, with a confusion of these external depressions, one might think there had been a dorsally and posteriorly directed evagination on the part of the blind end of the inner portion of the cleft. The dorsal part of this primitive tympanum is, however, somewhat enlarged.

The whole region of the external depressions is somewhat deeper in an 18 mm. embryo, and the ventral depression especially has become deep and narrow (Fig. 17). No other important changes are noticeable, except an increase in the obliquity of the plane of the partition, principally due to the deepening of the ventral depression.

When the embryo has reached the length of 25 mm. the ventral depression is much deeper (Fig. 18, b). It can now be called the exter-

nal meatus. Whereas its termination maintains the same, or nearly the same, relation to the pharyngeal cavity as before, it has approached much nearer to the inner portion of the cleft, inasmuch as the thickening of the walls of the head in this region has slightly straightened the latter, and brought its long diameter into a position more nearly perpendicular to the surface of the head. At the same time there has been a reduction in the thickness of the partition (primitive tympanic membrane) which separates the inner from the outer remnant of the cleft. This partition subsequently becomes still thinner (Fig. 20), but according to Kölliker and others it retains a considerable thickness during the whole of embryonic life.

To recapitulate, the external meatus is formed by the outward growth of the tissue constituting the walls of the first visceral cleft. The closure of the cleft is effected from its ventral edge toward its dorsal extremity by the gradual upgrowth of tissue, which in turn results from the fact that the fusion of the contiguous arches progresses dorsally. The position of the dorsal extremity, which is the last to close, is for some time marked by an external depression (*a*), but this afterwards becomes more shallow, whereas the ventral portion, which soon after the closure of the dorsal end of the cleft is indicated by only a shallow depression, gradually increases in depth, and ultimately forms the deep portion of the external meatus.

The tympanic membrane originates from tissue in the region where the cleft is first closed; it is not uniform in thickness at first, and it lies inclined to the surface of the embryo; afterwards its thickness is reduced, and at the same time becomes more uniform. Simultaneously the plane of the tympanic membrane is shifted, from a position approximately parallel to the surface of the head, to one more nearly perpendicular to that surface. The inner remnant of the cleft increases slightly in length, but probably not much, until the embryo is 18 mm. long; this, moreover, is not due to an actual evagination, but appears to be accomplished by the growth of the tissue forming its walls. Its blind end enlarges to form the tympanum, while the remaining less altered part forms the Eustachian tube.

The first cleft is closed at a much earlier stage than observers have hitherto claimed. The hyoid and mandibular walls come in contact along a line parallel to the surface of the embryo and a little nearer the external than the internal opening of the cleft. From the contiguous walls are proliferated cells which form the bridge across the cleft. Simultaneous with this process occurs the formation of the incipient auricle, the changes in the deeper portion of which soon separate the

remnant of the cleft into two distinct parts, a dorsal shallower and a ventral deeper part. Both of these persist: the ventral part is transformed into the deep portion of the meatus, and together with the superior half it also forms the cavity of the external ear. Therefore, as claimed by Reichert, the ventral division of the cleft plays the more important part in the formation of the external ear. In my observations I have been unable to find any evidence in favor of Günther's view that the walls of the cleft fuse in such a manner as to leave for a short period *two* openings into the pharynx. On the contrary, the bridge of tissue that closes the last remnant of the opening is a simple accumulation of cells, which forms an uninterrupted membrane of approximately uniform thickness. This remains for some time very thin, and might easily be ruptured even by as delicate a probe as a hair; moreover, the cleft does not show a definite division into a dorsal and a ventral part until the embryo is about 10 mm. long; but at this time the cleft has long been closed, although the bridge is still very thin. It is from these considerations that I have been led to believe that the two openings claimed by Günther were artificially produced by a rupture of the tissue forming the bridge.

As to the conclusions reached by Urbantschitsch about the manner in which the visceral fissures close, it is to be observed, in the first place, that his cross sections (*op. cit.*, Figs. 1–3) do not afford the least direct evidence that the first cleft remains pervious until it is reduced to a mere hole, for the sections only pass through the orbital process and the lower-jaw branch of the first arch. It is unfortunate for his claim, that he has not reproduced the sections which show that "the same condition that is encountered between the orbital process and the lower-jaw branch is found between each two of the arches." In the second place, the single section shown in his Fig. 4 is not in itself alone sufficient to prove that the cleft is not already closed by a continuous bridge of tissue. He calls this a frontal section: the regions of the embryo touched by the section seem, however, to indicate that it is not strictly frontal, but, on the contrary, quite oblique to that plane,— perhaps even nearer a sagittal than a frontal plane. The section is to all appearances approximately parallel to a tangent to the side of the head and neck in the region of the visceral arches and clefts, so that it cannot be safely inferred from the condition of the fissures in the plane of this section that they present the same condition in every part of their depth. The figures accompanying the present paper (Figs. 9, 10, 11) show how unreliable the conclusions based upon any single section, like that shown in Fig. 9, would have been. While, then, I do not doubt that the restriction of the fissure is largely accomplished, as

Urbantschitsch claims and as Reichert long ago stated, by the dorsal and ventral ingrowth of tissue, it remains none the less true, for the pig at least, that this is only a part of the process, and that an early fusion of the arches makes the first cleft impassable long before the reduction in the length of the fissure is effected by these mesodermic growths. Moreover, although I admit the dorsal ingrowth to be subsidiary to an increase in the thickness of the partition that closes the cleft, it helps only after the bridge has been formed by cells derived from the hyoid arch.

The conditions presented in the chick, as shown by Moldenhauer's studies, and those in the pig, are in many points strikingly similar; but it is the *interpretation* given to the facts by Moldenhauer which is at variance with my own conclusions. The real question at issue is this: Is any part of the tubo-tympanic sulcus a result of the direct metamorphosis of the first cleft, or is it rather the result of a secondary outgrowth from pharyngeal cavity? Moldenhauer defends the latter assumption, whereas I am convinced of the validity of the former. To answer the question, it seems to me only necessary to determine the extent of the tubo-tympanic sulcus in two directions, — the dorsal and the posterior.* According to his own figure (Moldenhauer, '77, Taf. VIII. Fig. 23), with which my own on the pig (Fig. 16) agrees in all essential matters, the dorsal limitation (blind end) of the sulcus corresponds quite accurately with the dorsal extent of the fissure before its closure. The depression of the ectoderm dorsal to his colliculus posterior, through which the lines *a b* pass in his Fig. 23, lie, according to his own description (p. 130), in the prolongation of this sulcus; but the depression in question corresponds approximately to the dorsal limit of the now closed cleft. That this depression does not subsequently grow deeper and thus become the external meatus, as has been supposed by some of the earlier observers, but is finally obliterated, can be no argument against its being the remnant of the dorsal region of the primitive cleft; if it is such, then it is certain that the sulcus tubo-tympanicus does not have a greater *dorsal* extension than would be expected if it were simply the remnant of the inner half of the first cleft. There is, then, no motive for assuming a secondary outgrowth in a *dorsal* direction.

As regards the anterior (upward, Moldenhauer) extent, it certainly must be admitted to be at first greater than that of the fissure; its posterior end, however, communicates at an early stage with the outside by

* Posterior and superior respectively, according to Moldenhauer's terminology.

means of the first cleft; in other words, the posterior (lower, Mold.) region of this sulcus is identical with the inner end of the fissure, which in turn is continuous with the pharyngeal cavity. The question, then, simply becomes, Which portion of this sulcus is converted into the Eustachian tube and drum, — the anterior or posterior? When it is observed that the greatest lateral extent of the sulcus is encountered in the cross sections (Moldenhauer's Figs. 23, 25) which lie *in the plane of the branchial furrow*, I think there need be no hesitancy in admitting that it is the *posterior* part of this sulcus which persists, and is immediately concerned in the formation of the drum and tuba; and if so, there can be no valid objection to considering these spaces as resulting from the metamorphosis of the inner edge of the first visceral cleft.

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EXPLANATION OF LETTERS.

a. Dorsal part of the first visceral cleft, from Hunt's depression to the point where it becomes continuous with the ventral depression of the cleft.
a. 2. The second visceral or hyoid arch.
a. 3. The third visceral arch.
b. The ventral portion of the cleft to its union with the dorsal part.
c. The inner portion of the first visceral cleft.
c'. The inner portion of the second visceral cleft.
c. 1. The first visceral or hyo-mandibular cleft.
c. 2. The second visceral cleft.
c. 3. The third.
d. Depressions separating the primary from the secondary elevations.
d'. Angle marking the limit between the cleft and pharynx.
d H. Depression described by Hunt.
d p. Dorsal depression of the first cleft.
e. Optic vesicle.
m. Mouth.
m d. Mandibular arch.
m d e. Dorsal mandibular elevation; the swollen root of the mandible.
m e. Meatus externus. (In early stages the external portion of the first visceral cleft.)

m e s. Mesoderm.
m v e. Ventral mandibular elevation.
m x. Maxillary branch of mandibular arch.
o. Otic vesicle.
p e. Primary elevation on the hyoid arch.
s d. The dorsal secondary elevation of the hyoid arch.
s v. The ventral secondary elevation of the hyoid arch.
v p. Ventral depression of the first cleft.

EXPLANATION OF FIGURES.

Fig. 1. Head and neck of an embryo pig 6 mm. in length.
Fig. 2. Side view of an embryo 8 mm. long, in the region of the clefts.
Fig. 3. Same view of an embryo 9 mm. long.
Fig. 4. Same, of an embryo 10 mm. long.
Fig. 5. Side view of the first cleft of an embryo 11 mm. long.
Fig. 6. The same region from an embryo 17 mm. long.
Fig. 7. The incipient auricle at a stage 19 mm. long.
Fig. 8. The same at a 25 mm. stage.

Figs. 9–11. Three successive sections tangential to the left side of the neck, cut nearly parallel to the sagittal plane, from an embryo 6 mm. long. The sections pass through the region of the first and second visceral clefts. The distance of the nearly parallel lines indicates the relative thickness of the ectoderm.

Fig. 12. The outlines of a series of sections through the region of the cleft of an embryo 8 mm. long. (Since the complete series is quite numerous, only a certain number have been selected for reproduction. Their positions in the series are indicated by the numbers accompanying each outline. The sections are cut somewhat obliquely to the plane of the cleft: they incline from above downwards and backwards. The successive sections from the left to the right correspond to successive planes from before backwards.)

Fig. 13. A cross section of an embryo 8 mm. long, which shows the bridge of epithelial cells that separates the inner from the outer portion of the cleft.

Fig. 14. A series of cross sections through the region of the first cleft of a 12 mm. embryo.

Fig. 15. Frontal section of the first cleft of a 12 mm. stage, showing the mesoderm which increases the thickness of the bridge.

Fig. 16. A series of sections from an embryo 16 mm. long, cut parallel to the cleft.

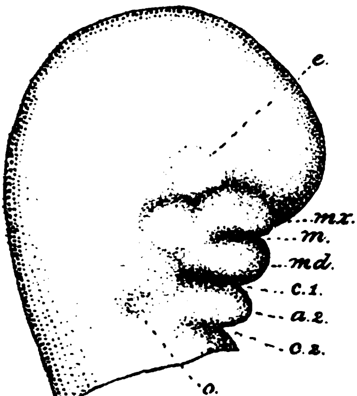
Fig. 17. A series of sections, also parallel to the cleft, from an 18 mm. embryo. They show a deepening of the ventral depression, and a change in the direction of the plane of the bridge which separates the inner from the outer portion of the cleft.

Fig. 18. Transverse section through the region of the ear from an embryo 25 mm. long. The bridge has become thinner, and its long axis is now nearly perpendicular to the surface of the head.

Fig. 19. A portion of the section shown in Fig. 20, more highly magnified.

Fig. 20. Section from a more advanced embryo (30 mm.), made in the same direction as in Fig. 18, but a little more posterior.

CAMBRIDGE, June, 1883.



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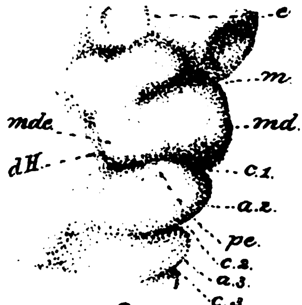

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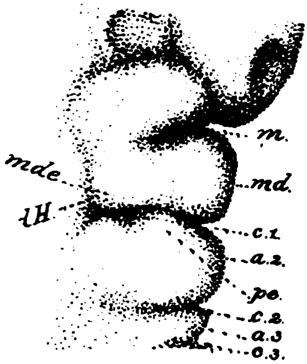

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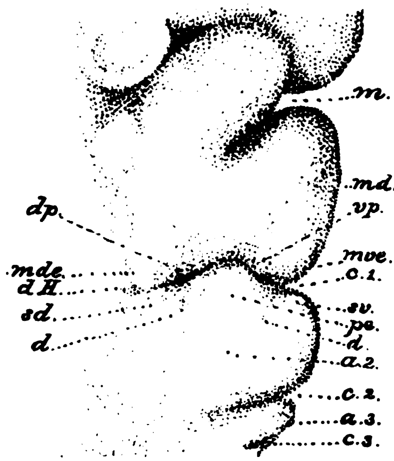

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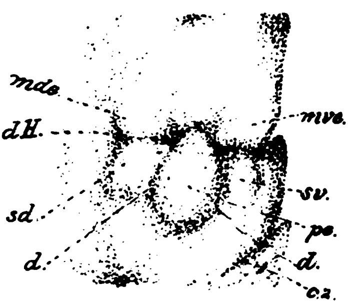

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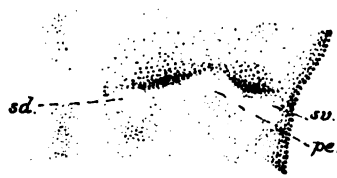

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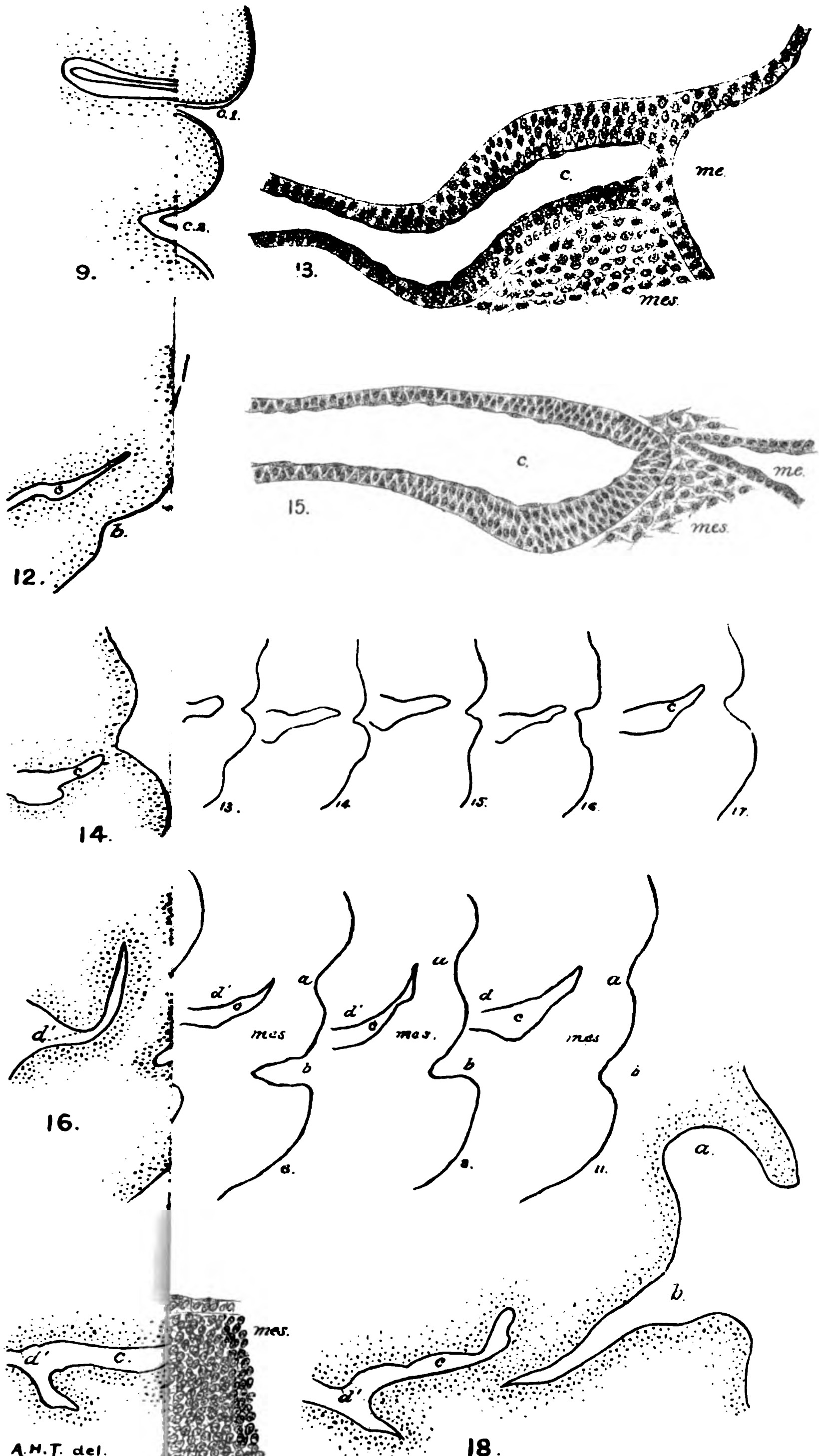
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IV.

THE FOSSIL WHITE ANTS OF COLORADO.

By Samuel H. Scudder.

Presented October 10, 1883.

The family of Termitina is represented in the tertiaries of Europe by twenty-nine nominal species. Hagen, however, asserts that several of those purporting to come from amber are in reality copal species; and this, with synonyms and species merely nominal, reduces the actual number to seventeen. It is doubtful if one of these, *T. Peccanæ* Massal., is a Termes at all, and if it is, its position cannot be further defined. The number may therefore be considered sixteen; besides this, a species has been indicated without name from the English tertiaries.

Of these sixteen, six come from amber, belonging to three genera (Calotermes, two species, Termopsis three and Termes one); six from Radoboj, also of three genera (Hodotermes two species, Termes two, and Eutermes two); and three from Oeningen, of two genera (Hodotermes two species, Termes one — the same as found at Radoboj). Besides these, there is a Calotermes from Rott, and a Hodotermes from Schossnitz.

The section comprising the genera having a branched scapular vein is therefore represented by eleven species (Calotermes three, Termopsis three — from amber only, Hodotermes five); while the section with simple scapular has only five species (Termes three, Eutermes two). The nominal and doubtful species (and, it might be added, most of the synonyms) fall into the latter section, and should doubtless increase it somewhat. As it stands, the first section has two thirds of the fossil species.

Thirteen of these sixteen species are entered in Hagen's *Monographie der Termiten;* the others have since been published; and it is noteworthy that of the eighty-four modern species contained in this monograph, fifty-five, or nearly two thirds, belong to the second section; in other words, only thirty-one per cent of the tertiary, but sixty-five per cent of the recent species, belong to the second section.

The additions to the tertiary Termite-fauna here made are in entire keeping with these statistics; six species are described, of which four belong to the first, and two to the second section, raising the number of tertiary species to twenty-two, or about one fourth the number of recent species.

Of these six species, three belong to a new extinct genus, apparently peculiar to America, but possibly including some of the species from the European tertiaries; another is referred doubtfully, from want of sufficient data, to Hodotermes, which has yielded species from Radoboj, Oeningen, and Schossnitz, as well as among modern types; while the other two probably fall into Eutermes, and are allied to, but considerably smaller than, the species from Radoboj placed with many modern types in the same genus. They are perhaps more nearly allied to, as they certainly agree better in size with, the two species of Termes found living in the neighboring valley of the Fontaine qui Bouille. Calotermes, which has furnished species from amber and the Rhenish basin, Termopsis, which has more fossil (amber) species than recent, and Termes proper, which is represented at Oeningen and Radoboj and in amber and the Rhenish basin, all seem to be wanting in the American tertiaries. The composition of the white-ant fauna of the ancient Florissant, to which locality the known American fossils are confined, differs considerably from that of the localities known in the European tertiaries, but resembles that of Radoboj more closely than it does any other, as will appear from the following table of representation.

First Division.

FLORISSANT.	RADOBOJ.
Parotermes insignis.	
" Hagenii.	
" fodinæ.	
Hodotermes ? coloradensis.	Hodotermes Haidingeri.
	" procerus.

Second Division.

FLORISSANT.	RADOBOJ.
	Termes pristinus.
Entermes fossarum.	Eutermes obscurus.
" Meadii.	" croaticus.

Out of one hundred and fifty-three specimens of amber white ants examined by Hagen, only a single larva and no soldier was found; all other fossil individuals have also been winged specimens; but it is worthy of special remark, that in the collection of twenty-six indi-

viduals from Florissant one is a larva. The scarcity of such forms, whether in amber or lacustrine deposits, is easily explained by the habit of life of these creatures.

The very presence of so considerable a number of Termitina (twenty-six specimens, six species*) in the Florissant beds is indicative of a much warmer climate formerly than the locality now enjoys. Only three species of white ants, and of these only one belonging to the section with branched scapular vein, have been recorded from the United States north of the Gulf margin, excepting on the Pacific coast, where one or two more extend as far north as San Francisco. Yet seventeen species in all are recorded from North America by Hagen in 1861, and some have since been added to the list; while his South American list (nearly all from Brazil) includes thirty-one species, of which five are repeated from the North American list. Florissant is situated in 39° N. Lat., and Hagen says that the family only rarely (*wenig*), and that only in the Northern hemisphere, extends beyond the fortieth degree of latitude. One species occurs as far north as Manitoba.

TABLE OF GENERA.

Scapular vein branched.	
Submarginal vein present	*Parotermes.*
Submarginal vein absent	*Hodotermes.*
Scapular vein unbranched	*Eutermes.*

PAROTERMES nov. gen. (πάρος, Termes, nom. gen.)

Head rather large, short-oval in form, almost as broad anteriorly as posteriorly, well rounded behind; eyes small, ocelli wanting; antennæ longer than the head, but shorter than the head and prothorax, slender, perhaps slightly broader in the middle than at either end, composed of about twenty equal joints, shorter than broad. Prothorax from a half to a third as long as the head, narrower than or only as broad as it, broader in front than behind, subquadrate, with the hinder angles rounded off. Wings slender and straight, subequal, less than half as long again as the body, four times as long as broad; basal scale obscure in most specimens examined, moderately large, as long as the prothorax, its costal margin convex; costal margin of wing straight nearly to the tip, which tapers to a well-rounded point; marginal and

* According to Hagen (Linn. Ent., XII. 244), no locality in the world has yielded more than nine species of living types; they so rarely number more than four, that he had formerly indicated this as the limit, so far as known.

mediastinal veins both present, the latter distinct and reaching nearly to the middle (sometimes only to the end of the basal third) of the costal border; scapular vein running parallel to the costal margin to the tip of the wing and emitting from five to seven very oblique gently curving superior branches at partly regular intervals, the second arising before the middle of the vein; it also emits a couple of inferior branches from opposite the base of two of the later branches which strike the apex of the wing, diverging from the main vein no more than the superior branches. Externomedian vein also running parallel to the costal margin throughout the greater part of the wing, and not so far removed from the scapular as the latter is from the costal margin; it has four or five simple or forked branches, mostly arising in the basal third of the wing, and with these branches takes a remarkably longitudinal course obliquely toward the hind margin and parallel to the inferior apical branches of the scapular vein; it therefore occupies the greater part of the wing. The internomedian vein is reduced to a very contracted area, consisting apparently of only a single forked vein or two in the narrowing basal part of the wing. The feeble character of the externomedian and internomedian veins, as well as of the inferior branches of the scapular vein, prevents their preservation on most of the fossils, and it is only in a few specimens that the whole or nearly the whole can be made out. There is apparently no network or reticulation anywhere on the membrane of the wing. The abdomen is large and ovate, generally broader than the rest of the body.

This genus, which is most nearly allied to Termopsis and Calotermes, differs from each of them in points wherein they differ from each other, and has some peculiarities of its own. It differs from Calotermes in its shorter wings (relative to the length of the body), which lack any fine reticulation, and in its want of ocelli. From Termopsis it differs in its slenderer but yet shorter wings, without reticulation, its uniform scapular vein, running parallel to the costa throughout and provided with fewer and straight branches. From both it differs in the presence of distinct inferior branches to the scapular vein, but especially in the slight development of the internomedian vein, the excessive area of the externomedian vein, and the course of the latter, which is approximated much more closely than usual to the scapular vein and emits branches having an unusually longitudinal course. These last peculiarities also separate this genus still more widely from Hodotermes, with which it agrees pretty closely in many points, and in which Hagen places most of the

larger Termitina described by Heer from the European tertiaries, although they do not appear to agree with the characteristics of the genus as given by him, and certainly approach in some of their features the peculiarities of the present genus. It is however impossible from Heer's figures alone to judge whether they are really more closely allied to Hodotermes or Parotermes; a nearer examination of the types themselves would perhaps decide; but at present Parotermes must be considered peculiar to the American tertiaries.

The species are all of pretty large size. They may be separated as follows: —

Abdomen considerably broader than the thorax.
- Wings produced at the apex; submarginal vein short; branches of the externomedian vein and inferior branches of scapular more oblique than the superior scapular branches . . . . 1. *P. insignis.*
- Wings rounded at the apex; submarginal vein long; branches of the submedian vein and inferior branches of the scapular as longitudinal as the superior scapular branches . . . . 2. *P. Hagenii.*

Abdomen no broader than thorax . . . . 3. *P. fodinæ.*

Parotermes insignis nov. sp.

Head broad oval, of pretty regular shape, but broadest in the middle of the hinder half, the front and hind border broadly rounded; there is a slight median longitudinal suture in the posterior half of the head. Eyes one fifth the diameter of the head, situated with the front margin slightly more distant from the front than from the hind border of the head and the outer margin just within or at the lateral margin of the head; they do not appear to project strongly above the surface. Antennæ scarcely so long as the head and prothorax together, composed of about twenty to twenty-two joints, the basal joints twice as broad as the stem, the others broader than long and equal throughout, not enlarged toward the middle of the antennæ.

Pronotum nearly twice as broad as long, as broad as the head, the front margin nearly straight with slightly rounded corners, the hind border and sides forming one nearly uniform broad semicircular curve; its surface appears to be flat, or at least there is no median impressed line. Mesonotum a fourth broader than long, with a distinct median impressed line, at least in the front half, subquadrate in shape, broadest in the middle of the front half, and tapering slightly and regularly behind, the front margin broadly rounded to the shoulder of the wing. Metanotum about as long as the mesonotum and of a similar shape, but tapering more rapidly behind, and likewise with a median impressed line more distinct anteriorly.

Abdomen obovate, broad and about equally rounded at either end, in the middle nearly half as broad again as any other part of the body, in length just about equalling the entire thorax. Abdominal appendages obscurely seen in a single individual, where they are tolerably stout, tapering slightly, very bluntly terminated, and about as long as the last abdominal segment.

Legs very short, the tibiæ being shorter than the width of the thorax, and armed at tip with a pair of short straight spurs; tarsi not more than half as long as the tibiæ, but the separate joints are not determinable on any of the specimens.

Wings four times as long as broad, the middle of the front pair reaching the end of the abdomen, long and very regularly obovate, the only difference in the form of the two extremities being in the gentler tapering of the base, and the straighter course of the costal margin next the base. The basal scale is triangular, about as long as the mesonotum, its costal and outer margins each a very little convex. The scapular vein, its superior branches, and the mediastinal, are stout, while the other veins are very feeble and only appear under favorable preservation. The submarginal vein * is crowded against the margin, but does not run fairly into it before the end of the basal fifth of the wing. The mediastinal vein terminates a short distance before the middle of the wing. The scapular vein runs at only a short distance from and parallel to the margin, and emits from five to eight superior branches running in an extremely longitudinal course to the costa; usually the first branch is thrown off almost as far out as the middle of the second quarter of the wing, but where the branches are numerous three branches are thrown off before the middle of the wing; in addition to the superior veins two inferior veins are emitted in the apical third of the wing, and strike the lower margin of the wing just below the apex. The externomedian vein runs subparallel to, but a little divergent from, the scapular, and nearly as far from it as it is from the costal margin, emitting four inferior simple or forked branches which cover the greater part of the hind border with their nervules; from near the middle of the wing a superior branch is also emitted, which is soon lost. The internomedian vein is forked, and strikes the margin near the middle of the basal half.

Although in the number of branches to the scapular vein the speci-

* What I here call the submarginal vein is the short simple vein, sometimes present in, at other times absent from Termitina, which precedes the mediastinal vein. Hagen calls it the first branch of his subcosta.

men showing the wings most clearly (No. 7752) differs considerably from the others, the vein commencing to branch at a considerably earlier point, all the specimens agree so well in every other particular that these would appear to be individual variations. It is the largest species of the genus.

Length of body, 11.5 mm.; breadth of thorax, 2.5 mm.; of abdomen, 3.3 mm.; length of antennæ, 4.25 mm.; of front wing, 13.3 mm.; breadth of same, 3.35 mm.; length of middle tibia, 2 mm.; of tarsi, 1.25 mm.; of abdominal appendages, 0.65 mm.

Florissant. 4 specimens. Nos. 400, 7752, 9041, 14400.

Parotermes Hagenii nov. sp.

Head roundish obovate, very regularly rounded, scarcely half as long again as broad, broadest at the eyes, which are scarcely behind the middle, and are deeply set, their outer border projecting but little beyond the contour of the head. Antennæ nearly as long as head and pronotum taken together, composed of about twenty-six joints, subequal beyond the base, a little tapering at the tip.

Pronotum more than twice as broad as long, fully as broad as the head, the front margin slightly concave, the hind border and sides forming a regular broad curve. Mesonotum and metanotum shaped exactly as in *P. insignis*, and with a similar impressed line.

Abdomen obovate, but with more parallel sides than in *P. insignis*, being only a little broader than the thorax, and nearly as long as the rest of the body, including the head. Abdominal appendages tolerably slender, equal, bluntly pointed, composed of five or six joints, the last of which appears to be two or three times as long as the others, which are equal; the whole is about half as long as the pronotum.

Legs short, but longer than in *P. insignis*, the tibiæ being about as long as the width of the thorax, but they are imperfectly preserved on all the specimens.

Wings a little more than four times longer than broad, the middle of the front pair scarcely reaching the extremity of the abdomen, broadest in the middle, tapering almost as much apically as basally, the tip roundly pointed, the costal margin pretty straight until shortly before the tip, the lower margin broadly curved. The basal scale is of the same shape and size as in *P. insignis*, but with a stronger costal curve. The scapular vein and its superior branches are stout, its inferior branches and the veins below feeble, so as only to appear under favorable circumstances, being visible in only half of the speci-

mens before me. The submarginal vein of the front wing terminates at about the middle of the basal half of the wing, and about opposite the origin of the first superior scapular branch. The mediastinal vein extends about to the middle of the wing, both in the front and hind wings. The scapular vein is related to the margin exaçtly as in *P. insignis*, and has five or six superior branches on the hind wing, six or seven on the front wing; on the front wing they originate at subequal distances apart, commencing usually at about the middle of the basal half of the wing, but when there are but six branches (which appears to be less commonly the case) the first originates at a greater distance from the base; on the hind wing there is greater irregularity; in one specimen there are five branches on the left hind wing, the first originating beyond the middle of the wing, while on the right wing there is an additional vein, originating far before the second, at the middle of the basal half of the wing; in another specimen (No. 8250) with only five veins, the basal branch originates somewhat beyond the middle of the basal half of the wing, and the others follow at subequal intervals; besides these superior, there are two inferior nervules arising, the first at the end of the middle third of the wing, opposite a superior branch, and the second opposite the succeeding branch; sometimes a third vein appears beyond these; after parting from the scapular vein these take a longitudinal course and terminate at the tip of the wing. The externomedian vein runs subparallel to the scapular, diverging slightly from it and being as far from it as it is from the costal margin; it emits two or three inferior branches, the last scarcely beyond the middle of the wing, the basal ones of which appear to be forked, but all having an unusually longitudinal course, being only slightly deflected toward the lower margin. Nothing can be said of the internomedian vein.

This species differs from *P. insignis* by its more laterally disposed eyes, rounder head, differently shaped wings, more longitudinally disposed branches of the externomedian vein, and longer and narrower abdomen.

Length of body, 10.5–12, av. 11 mm.; breadth of thorax, 2.1 mm.; of abdomen, 2.6 mm.; length of antennæ, 4 mm.; of front wing, 13.5–15.5, av. 14 mm.; breadth of same, 3.35 mm.; length of middle tibia, 1.65 mm.; of abdominal appendages, 0.65 mm.

Florissant. 7 specimens. Nos. 4629, 4652, 5224, 6030, 8250, 8616, 14167.

PAROTERMES FODINÆ nov. sp.

Head oblong obovate, half as long again as broad, the eyes large, circular, about one fifth the diameter of the head, slightly projecting beyond the sides, the anterior edge near the middle of the head.

Pronotum transversely lunate, as broad as the head, less than twice as long as broad, the front margin regularly and considerably concave, the hind margins and sides forming one uniform strongly convex curve, the anterior lateral angles rounded off. Meso- and metanotum obscurely preserved, but apparently formed much as in the other species, the mesonotum being of about the same width as the pronotum.

Abdomen rather long and comparatively slender, scarcely if at all exceeding in width the parts in front, the sides being unusually parallel, the tip well rounded, the whole as long as the rest of the body. Abdominal appendages very small, stout, being only a little more than twice as long as broad, largest in the middle, and tapering either way, the tip blunt, the whole not longer than the diameter of the eye.

Legs poorly and partially preserved in a single specimen, showing them to be much as in *P. Hagenii*, the hind tibia being only a little shorter than the width of the mesothorax.

Wings four times as long as broad, the middle of the front pair reaching the tip of the abdomen; the exact form cannot be made out, but the costal margin is straight until very near the tip, and the hind border appears to be uniform and to make the wing slightly broadest just beyond the middle. The submarginal vein is unusually long, running into the costa only a little before the middle of the wing. The mediastinal terminates not far beyond the middle. The scapular vein has five or six branches in the front wing, generally five in the hind wing, the first appearing always to originate at the end of the basal third of the wing. The inferior nervules of this vein and the course of the branches of the veins below cannot be determined in any of the specimens, but there are faint indications of their presence, and nothing in them appears to distinguish this species by any marked peculiarities from the others of the genus.

This species differs from the others here described in its considerably smaller size, slender abdomen, and much smaller abdominal appendages.

Length of body, 9 mm.; breadth of thorax, 2 mm.; length of front wing, 13 mm.; breadth of same, 3.25 mm.; length of hind tibia, 2 mm., of abdominal appendages, 0.25 mm.

Florissant. 4 specimens. Nos. 1247, 1253, 7608, 11190, and 14391.

HODOTERMES Hagen.

Hagen refers to this genus two fossil species from Oeningen and two from Radoboj. Assmann also describes a species from Schossnitz, and one of the Florissant white ants is referred here doubtfully. The fossil therefore nearly equal in number the living species, which are all inhabitants of the Old World, the most northern species being found in Egypt.

Hodotermes? coloradensis nov. sp.

Metanotum considerably narrower than the mesonotum, as long as broad, tapering posteriorly, the front border straight, the hind border rounded.

Abdomen ovate, stout, less than twice as long as broad, the sides full, as broad as the mesothorax, posterior extremity rounded. Abdominal appendages long and slender, half as long as the metanotum, composed of at least six or seven joints, slightly tapering, terminating very bluntly.

Wings very long, the middle of the front pair lying far beyond the tip of the abdomen. Submarginal vein absent from all the wings. Mediastinal vein terminating at the middle of the front border. Scapular vein parallel to the front margin, with at least four branches in both wings, and in the front pair pretty certainly five branches, and perhaps six; the first branch originates in the front wing at the end of the basal fourth of the wing, in the hind wing a little farther out.

This species is readily distinguished from all the other fossil Termitina of North America by its very great size, the length of the wings being double that of any other. Although the specimen is very imperfect, the tip and lower half of the wings being absent, as well as the head, prothorax, and legs, it differs so much from the species of Parotermes, in the absence of the submarginal vein and the great length of the abdominal appendages, that it cannot probably be associated with them generically. In size and general appearance it agrees so fairly with the tertiary species described by Heer, referred to Hodotermes by Hagen, that I place the species provisionally in the same genus, with which (as with all other genera so far as I know in which the structure of the wings would allow it to be placed) it differs by the great length of its anal appendages.

Length of body as preserved, 9 mm. (probably it reached about 12); of abdomen, 6 mm.; breadth of same, 4.5 mm.; length of forewing,

23 mm. or more; of abdominal appendages, 1.25 mm.; breadth of same, 0.3 mm.

Florissant, No. 6010.

EUTERMES Heer.

The remaining species fall into the division of Termitina in which the scapular vein is unbranched, and it is uncertain whether they should fall in Termes proper or in Eutermes, the veins below the scapular being in all cases poorly preserved or wholly obliterated. The limited number of antennal joints in such as have these preserved sufficiently for examination, and the occasional indication of a broad subscapular field in others, leads rather to the presumption that they should be placed in Eutermes. Two species have been found at Florissant. The genus has been well known in a fossil state, four species having been described from Radoboj in Croatia, and five from Prussian amber. Indeed, the genus was first founded upon fossil species, but it was soon seen that many living forms belonged to the same group. The existing species, some thirty in number, belong almost exclusively to the tropics, and especially to those of the southern hemisphere.

The two species of Eutermes which have been found at Florissant may be separated by the following features:—

Head broader behind than in front, scarcely half as long again as broad.
Pronotum semicircular, the posterior curve uniform. . . . 1. *E. fossarum.*
Head not broader behind than in front, fully half as long again as broad.
Pronotum very short, the hind margin more or less truncate. 2. *E. Meadii.*

EUTERMES FOSSARUM nov. sp.

Head very regularly obovate, a little broader behind than in front, nearly half as long again as broad, its posterior border well rounded. Eyes rather small, situated in the middle laterally, projecting but little. Antennæ scarcely if any longer than the head, rather stout, enlarging away from the base, composed apparently of less than fifteen joints.

Pronotum as broad as the head and twice as broad as long, semicircular, the front border scarcely concave, the front margins slightly rounded. Meso- and metanotum as broad as pronotum, quadrate, equal, about half as broad again as long.

Abdomen somewhat longer than the rest of the body, and slightly

broader than the thorax, with gently rounded sides and well-rounded tip; no appendages are discoverable on any of the specimens.

Legs poorly preserved on all specimens; apparently they are of medium length.

Wings rather more than four times as long as broad, the middle of the front pair not reaching the tip of the abdomen, very uniform and regular, of nearly equal breadth throughout the middle two-thirds, the costal margin straight until just before the tip. Scapular vein parallel to the margin, the subcostal area infumated; veins below the scapular not determinable. The basal scale appears to be small, broad, triangular, its costal border swollen.

Length of body, 6.5–7.5, av. 7.15 mm.; of abdomen, 3.5–4.5, av. 4.15 mm.; breadth of pronotum, 1.2 mm.; of abdomen, 1.5 mm.; length of antennæ, 1.2 mm.; of front wing, 7.75–9.25, av. 8.25 mm.; breadth of same, 2 mm.

Florissant. 5 specimens. Nos. 2329, 6049, 7393, 11752, 14980, three of them in pretty good condition.

EUTERMES MEADII nov. sp.

Head very regularly obovate, broadest just behind the middle, where the small eyes, scarcely projecting, are situated, not broader behind than in front, the hind margin strongly rounded, the whole fully half as long again as broad. Antennæ nowhere well preserved, but apparently longer and with more numerous joints than in *E. fossarum*.

Pronotum as broad as the head (?) and very short, probably more than twice as broad as long, the hind margin not forming with the sides a continuous curve, but in its middle half only slightly convex. Meso- and metanotum quadrate, broader than the head, the mesonotum somewhat the larger, at least half as broad again as long.

Abdomen rather stout, longer than the rest of the body, the sides nearly parallel, the tip broadly rounded, and, as far as can be made out, unprovided with terminal appendages.

Legs moderately long and stout, the tibiæ armed with a pair of spines at apex, the front tibiæ about as long as the pronotum.

Wings long, slender, and uniform, four times or slightly less than four times as long as broad, the middle of the front pair reaching the tip of the abdomen, broadest at or slightly beyond the middle, the lower border slightly arcuate throughout. Costal margin straight in the basal three-fourths of the wing. Scapular vein parallel to the margin, the subcostal area scarcely infumated. Veins below the scap-

ular not determinable. Basal scale small, triangular, equilateral, the sides straight excepting the costal, which is very slightly convex and prominent.

This species differs from the preceding by its slightly smaller size, squarer pronotum, and differently shaped head.

Length of body, 5.25–7, av. 6.3 mm.; of abdomen, 2.8–3.5, av. 3.2 mm.; breadth of abdomen, 1.5 mm.; length of wing, 7.5–8 mm.; breadth of same, 2 mm.

Florissant. 4 specimens. No. 19 (Coll. T. L. Mead), and Nos. 31, 1203, 8062.

A single specimen of a wingless white ant has been found, apparently belonging to this species or to *E. fossarum*. It measures 3.75 mm. in length, and is of the ordinary form of the worker, with rounded head and constricted prothorax, bearing a general resemblance to the only other known fossil termite larva, figured in Berendt's work, but has the head more produced anteriorly and the abdomen less distended.

Florissant, No. 6100.

Illustrations of these species will appear in a Government Report in preparation.

V.

THE ZODIACAL LIGHT.

By Arthur Searle.

Presented October 10, 1883.

At the outset of any inquiry into previously neglected phenomena, the observations or experiments which can be made are necessarily somewhat vague. The questions to which we endeavor to obtain replies are drawn up more or less at random, and this is even more true of the hypotheses by which we relieve the monotony of our first observations. A considerable improvement in the conditions governing our inquiries will be made when we begin to discover the details to which our attention should be directed in order to arrive at the more general knowledge originally desired. But the discovery of these details usually demands a patient examination of the confused mass of material first collected by observation. It is not so likely to be forwarded by the formation of new hypotheses, although it is undoubtedly true that a lucky guess may give a fortunate direction to our work, upon which we should have been long in deciding if we depended only upon the study of what had already been observed. Still, it is never advisable to neglect this study in the hope that it can be saved by guessing.

For these reasons, it has seemed to me worth while to collect, and partially to reduce, upon a uniform system, the published work of several observers of the zodiacal light. I have confined my attention for the present to their evening observations, as the morning observations would in any case require separate consideration, and as it has been difficult to find time, under the pressure of other occupations, for even the limited discussion herewith presented. From Serpieri's study of the observations of Jones (to be further mentioned below) we have, moreover, some means of comparing the most important published series of morning observations with the evening observations of the same observer.

The data here collected relate to the approximate position of the zodiacal cone in the visible hemisphere of the sky, to the elongation

of the vertex, and to the latitudes of the northern and southern boundaries at successive elongations 30° apart. The term "elongation" will be used throughout this discussion to denote a difference of longitude between the Sun and some other point, not the direct angular distance of that point from the Sun. Since the zodiacal light, however it may be produced, has plainly some relation both to the Sun and also to some great circle not much inclined to the ecliptic, the arrangement of the observations according to elongation (in the sense just stated) appears to be the most natural which can be adopted. The interval of 30° is arbitrary. The knowledge of the observations gained by reducing them now inclines me to think that 20° would have been preferable, although it would have increased the labor of the work; but I could not have the information necessary to settle this question at the beginning of the reductions.

In the following pages, I shall have occasion to cite a number of works, the titles of which are here given, with the abbreviations afterwards used to designate them. Figures following an abbreviation will indicate the page of the corresponding work to which reference is made.

A. Argelander, Aufforderung an Freunde der Astronomie. (Pp. 122–254 of Schumacher's Jahrbuch für 1844.)

C. Celoria, Sopra alcuni Scandagli del Cielo. (Pubblicazioni del Reale Osservatorio di Brera in Milano, N. XIII.) Milano, 1877.

D. Dechevrens, La Lumière Zodiacale. Zi-Ka-Wei (China), 1879.

G. Geelmuyden, Remarques sur la Théorie de la Lumière Zodiacale. (Separataftryk af Archiv for Mathematik og Naturvidenskab.) Kristiania (1882 ?).

*H. Heis, Zodiacallicht-Beobachtungen in den letzten 29 Jahren 1847–1875. I. Veröffentlichung der königl. Sternwarte zu Münster. Münster, 1875.

Hb. Humboldt, Cosmos, Vol. I. (Bohn's Scientific Library.) London, 1849.

*Jj. Jones, Observations on the Zodiacal Light. (United States Japan Expedition, Vol. III.) Washington, 1856.

Jq. Jones, Observations at Quito. (Am. Journal of Science for November, 1857, Vol. XXIV. pp. 374–385.)

L. Loewy, Remarques sur la Méthode proposée par M. le Professeur Pritchard pour la Mesure de l'Éclat des Astres. (Monthly Notices of the Royal Astronomical Society, Vol. XLII. pp. 91–94.)

La. Lewis, Note on the Zodiacal Light. (Am. Journal of Science for December, 1880, Vol. CXX. pp. 437–445.)
M. Müller, Photometrische Untersuchungen. (Publicationen des Astrophysikalischen Observatoriums zu Potsdam. Nr. 12. Potsdam, 1883.)
*S. Schmidt, Das Zodiacallicht. Braunschweig, 1856.
Sp. Serpieri, La Luce Zodiacale studiata nelle Osservazioni di G. Jones. (Memorie della Società degli Spettroscopisti Italiani. Appendice al Volume V., Anno 1876, pp. 49–161.)
T. Observations de la Lumière Zodiacale à Toulouse. Notes de M. Gruey. (Comptes Rendus des Séances de l'Académie des Sciences, Tom. LXXIX. pp. 1250–1253; Tom. LXXX. pp. 903–906.)
W. Wolf, Description du Groupe des Pléiades. (Annales de l'Observatoire de Paris. Mémoires, Tom. XIV. Deuxième Partie. Pp. A. 1 — A. 81.)

Tables X. to XXXIV. inclusive, in the Appendix following the present discussion, exhibit the data obtained from the works by Jones, Heis, and Schmidt, which are marked with asterisks in the list above. Besides his own observations, Heis reports others by Weber, Eylert, and Neumayer. Notwithstanding the small number of observations by Eylert and Neumayer, the geographical positions at which they were taken make them at least interesting, if not very conclusive. It may appear superfluous to print the results of the separate observations, as is done in Tables X., XI., and XII. But while some readers may be dissatisfied with the subsequent course taken in the reductions, they may still be able to make use of the separate observations, as here arranged upon a uniform system for each observer. I have myself had occasion to regret that Serpieri was prevented by want of space (Sp. 61) from publishing the numerical tables by which he had represented all the observations of Jones.

It has also seemed desirable to include in the Appendix a few tables and a small chart intended to facilitate approximate determinations of the position of the zodiacal light in the visible hemisphere. To make such determinations with accuracy seems needless in our present state of knowledge with regard to the zodiacal light, especially as the time of the observations is often given without much precision. The Appendix contains a description of all the tables included in it, which will make it unnecessary to consider them further in this place. I may accordingly pass at once to the conclusions which they suggest to me.

The first deduction which Jones himself made from his observations (Jj., Introduction, xvi.) was that the place of the zodiacal light with respect to the ecliptic depended upon the position of the ecliptic in the visible hemisphere; so that the light was comparatively deficient on the lower side of the ecliptic. As Jones states it, when he was north of the ecliptic, the main body of the light was also north of it; when he was south of the ecliptic, so was the main body of the light; when he was nearly on the ecliptic, the light was equally divided by the ecliptic, or nearly so. He also found that in a large majority of cases a change in the zenith distance of the pole of the ecliptic during a single evening was accompanied by a progressive change of the zodiacal light, in accordance with the rule just stated.

A cause, obviously tending to produce an effect of this kind, is well known to exist. The atmosphere of the Earth absorbs light with increasing efficiency as the line of sight descends from the zenith towards the horizon. Accordingly, the brightness of the zodiacal light on the lower side of the ecliptic should be diminished relatively to that of the light at the same distance from the ecliptic on the upper side. But before accepting this explanation of the law discovered by Jones, we must see whether the law itself is confirmed by the experience of other observers, and whether the known amounts of atmospheric absorption at different altitudes exhibit a reasonable degree of correspondence with the observed effects. The subject has been debated by Geelmuyden and Groneman (G. 83), but seems to need the different treatment here proposed.

A general view of the result for the elongation 60° is afforded by Table I., below. The first two columns, headed "Observer" and "Group," relate to the arrangement of the observations in the final tables of the Appendix. The "Diffuse" Light observed by Jones is not here taken into consideration. The next four columns contain the latitude of the observer's station; the zenith distance of the north pole of the ecliptic, here called the inclination of the ecliptic; the elongation of the zenith, by which is meant the excess of its longitude over that of the Sun; and, finally, the zenith distance of the Sun. The next column gives the number of observations upon which the preceding results directly or indirectly depend, as is explained in the Appendix. The remaining columns relate to the position of the zodiacal light with respect to the ecliptic, 60° from the Sun. The first of these columns contains the number of observations upon which the result depends. A strict reduction would have required the number of the preceding column always to agree with this; that is, the data for the position of

the ecliptic in the visible hemisphere should have been calculated separately for the separate observations. As it is, they apply only approximately to the mean results at particular elongations; but when these results are derived from considerable numbers of observations, the approximation will be sufficient for the present purpose. Means are provided in the Appendix for the further reduction of the work, if that should appear desirable, but I have not hitherto found time to attempt it.

The column of numbers is followed by two columns giving the latitude of the axis of the light, and its half extent in latitude. By the latitude of the axis is meant the mean of the latitudes of the northern and southern boundaries. These data are derived exclusively from those observations from which the latitude of the axis can be separately determined. In the cases of Heis and Weber the number of observations for the half extent in latitude is sometimes slightly inferior to that here given, which relates to the latitude of the axis, as will be seen in Table XXVIII. The next two columns of Table I. contain the zenith distances of the northern and southern boundaries corresponding to the previous data. They are followed by the amounts of atmospheric absorption due to each of these zenith distances according to Müller, expressed in terms of stellar magnitude by dividing each logarithm of the original table (M. 59) by 0.4. The last column of Table I. gives the difference between the amounts of absorption in the preceding columns, expressed as a positive quantity when the absorption at the southern boundary exceeds that at the northern.

In the discussion of these results I shall first consider the question raised by Serpieri (Sp. 111), whether Jones was right in referring the apparent changes in the place of the light to the corresponding changes in the place of the ecliptic in the visible hemisphere, and whether they ought not rather to be referred to the geographical position of the observer in latitude. In the case of Jones, which Serpieri was discussing, the changes in the place of the ecliptic are very generally in accordance with the movements of the observer. But the second group of observations in Table I. exhibits a decided interruption of this accordance. Since it may perhaps be conjectured that the method of reduction is here at fault, I have determined the position of the ecliptic for each of the twenty-four observations of this group. The new reduction makes no change in any of the data, except that the mean result for the "elongation of the zenith" becomes 122°, instead of 123°, as in the table. This alteration is entirely insignifi-

TABLE I.

Observer.	Group.	Lat. of Obs.	Incl. of Ecl.	Elong. of Zen.	Z. D. of Sun.	Total no. Obs.	Elongation 60°.							
							No.	Lat. of Axis.	Half Ext.	Z. D. N.	Z. D. S.	Absorption. N.	Absorption. S.	Diff. Absorption.
		°	°	°	°			°	°	°	°			
Jones	1	+30	43	125	113	144	69	+4 9	8.0	63	74	0.28	0.60	+0.32
"	2	+21	53	128	116	58	24	+3.2	7.6	61	71	0.25	0.48	+0.23
"	3	+34	65	124	121	52	46	+1.9	6.6	63	69	0.28	0.42	+0.14
"	4	+27	79	124	123	87	70	+0.9	8.8	60	64	0.23	0.30	+0.07
"	5	+22	88	127	127	42	16	+0.5	7.8	67	67	0.36	0.36	0.00
"	6	+ 4	104	118	117	39	35	−1.6	8.1	60	55	0.23	0.17	−0 06
"	7	−30	142	131	114	26	20	−3.4	7.6	81	70	1.07	0.45	−0.62
Heis	1	+52	46	129	117	20	20	+4.4	10 2	64	78	0.30	0.82	+0.52
"	2	+52	53	117	111	68	68	+2.5	10.2	55	68	0.17	0.39	+0.22
"	3	+52	60	116	112	95	85	+2.5	9.5	54	65	0.16	0.32	+0.16
Weber	1	+52	43	116	107	7	6	+2.8	12.3	56	75	0.18	0.65	+0.47
"	2	+52	54	114	110	85	35	+2.7	10.4	54	66	0.16	0.34	+0.18
"	3	+52	60	114	110	45	45	+2.1	8.6	58	68	0.15	0 28	+0.13
Eylert; Neumayer	1	+30	63	120	117	5	5	+3.0	8.6	59	67	0.22	0.36	+0.14
"	2	+15	77	119	118	3	3	+2.7	6.0	57	60	0.19	0.23	+0.04
"	3	−11	91	118	118	7	7	+0.6	5.7	58	58	0.20	0.20	0.00
"	4	−31	104	111	110	9	9	−1.2	4.0	54	51	0.16	0.13	−0.03
Schmidt	1	+50	47	124	114	4	2	+2.0	5.5	65	78	0.32	0.56	+0.24
"	2	+50	55	130	121	11	10	+2.0	4.4	70	75	0.45	0.65	+0.20
"	3	+50	61	116	112	1	15	+2.1	4.0	57	61	0.19	0.25	+0.06
"	4	+42	69	106	105	7	6	+1.3	2.7	47	50	0.10	0.12	+0.02

cant, and makes no noticeable difference in the result for atmospheric absorption. It will be seen that the observations of this group were made in a more southern latitude than those of the next two groups, and at about the same latitude as that in which the observations of the fifth group were made. Meanwhile, the apparent shifting of the axis follows the progressive change of the inclination of the ecliptic, entirely in accordance with the original theory of Jones. In order to form an independent judgment upon the subject, the work of Serpieri must be consulted, and the graphical arrangement of the observations, by which he supports his argument, must be examined. My own conclusion is that the view taken by Jones was correct.

All the evening observations of Heis and of Weber were made near the fifty-second parallel of latitude, where the zodiacal light can only be seen for the few months during which the zenith distance of the north pole of the ecliptic is near its maximum at the time of observation. Under more favorable circumstances the fixed stations of these observers would have aided us materially in distinguishing the cause of the apparent movement of the zodiacal light in latitude. So far as it goes, the evidence of Heis is in favor of a change due to an altered position of the ecliptic, or rather to the resulting difference in atmos-

pheric absorption; for while the inclination of the ecliptic changes by seven degrees in passing from each group of observations to the next, the change in the final column of Table I. is 0.30 between Groups 1 and 2, and only 0.06 between Groups 2 and 3. The corresponding changes in the latitude of the axis are 1°.9 and 0°.0. The evidence of Weber, taken without regard to the number of observations in each group, would not support the hypothesis of regular change; but the number of observations in his first group is only six, and this circumstance leaves us without any distinct result in his case. The mean result for Heis and Weber, with equal weights for the separate observations, would indicate a progressive change in the latitude of the axis.

The small number of the observations of Eylert and Neumayer makes the result from them inconclusive. It is of interest, because we have no other observations made in southern latitudes except those of Jones, and it tends to confirm the principle established by that observer. But in this instance a change in terrestrial latitude accompanies that of the position of the ecliptic.

Schmidt's observations, if they were sufficiently numerous, would confirm Serpieri's hypothesis. The axis remains at two degrees of north latitude until the observer changes his station to Italy, when it begins to approach the ecliptic. But neither of the four groups contains many observations, and there are some peculiarities in Schmidt's results, to be considered hereafter, which may partially account for the discordance between them and some of the others.

Setting aside, for the present, the consideration of atmospheric absorption, my conclusions from the observations thus far considered are, first, that the experience of Jones with regard to the shifting of the light is confirmed by that of other observers; secondly, that he was right in connecting the change with the altered position of the ecliptic in the visible hemisphere, rather than with the change in terrestrial latitude from one place of observation to another.

In the absence of the strict reduction mentioned above (p. 149), only a very general conclusion can be drawn from the observations at the elongations 30° and 90°, since their number is often comparatively small. It will appear by inspection of Tables XXV., XXVIII., XXXI., and XXXIV. that the observations of Jones, Heis, and Weber, made at these elongations, agree on the whole with the results obtained at the elongation 60°. The other observers furnish very little material for a conclusion, and the results are irregular.

We have still to consider the observations by Jones of what he

called the "Diffuse" Light. Only those at the elongation 90° are sufficiently numerous, in comparison with the total numbers of observations used in determining the successive positions of the ecliptic, to allow us to attach much significance to the result from them. Still, the observations at 60° may be worth examining, and they are accordingly included in Table II. The first two columns of this table give the numbers of the successive groups of the observations of Jones and the total number of observations belonging to each group. These data are repeated from Table I. It is unnecessary to repeat the corresponding data for the position of the ecliptic. The rest of Table II. consists of two parts, relating to the "Diffuse" Light at the respective elongations 60° and 90°. Each part gives data corresponding to those for the "Stronger" Light found in Table I.

TABLE II.

Group.	Total no. Obs.	Elongation 60°.								Elongation 90°.							
		No.	Lat. of Axis.	Half Ext.	Z. D.		Absorption.		Diff. Absorption.	No.	Lat. of Axis.	Half Ext.	Z. D.		Absorption.		Diff. Absorption
					N.	S.	N.	S.					N.	S.	N.	S.	
1	144	86	+5°.9	21°.8	54°	86°	0.16	2.04	+1.88	82	+5°.1	19°.7	84°	67°	0.04	0.36	+0.32
2	58	15	+6.8	24.2	52	80	0.14	0.98	+0.84	26	+1.6	16.1	85	60	0.04	0.23	+0.19
3	52	22	+2.0	21.7	58	76	0.20	0.70	+0.50	44	+3.8	15.5	83	50	0.04	0.12	+0.08
4	87	48	+1.7	21.6	62	70	0.26	0.45	+0.19	50	+2.2	17.8	45	53	0.09	0.15	+0.06
5	42	16	+3.8	17.4	63	69	0.39	0.42	+0.03	19	+1.3	15.5	38	39	0.05	0.06	+0.01
6	39	17	—1.9	20.8	66	56	0.34	0.18	—0.16	17	—2.9	15.1	38	27	0.05	0.02	—0.03
7	26	5	—6.8	19.4	88	59	3.10	0.22	—2.88	7	—4.3	18.3	75	44	0.65	0.08	—0.57

These results exhibit more irregularity than those found for the "Stronger" Light, but seem on the whole to agree with them. The view of Serpieri, however, is supported by the observations of the "Diffuse" Light at the elongation 90°. The observations of the second and fifth groups were made, as we have seen, in about the same terrestrial latitude, and give approximately the same value for the "latitude of the axis," while larger values are furnished by the third and fourth groups, the observations of which were made at more northern stations. It will be sufficiently apparent by inspection of Table X. that no very great change would be made in the assumed position of the ecliptic, or of the observer's latitude, by computing them for the second group from those observations only in which the latitudes of the boundaries of the "Diffuse" Light were observed at

the elongation 90°. It is also apparent that the small mean value here obtained for the "latitude of the axis" results from the extension of the "Diffuse" Light, near its vertex, towards the south, which Jones repeatedly observed towards the end of October, 1853. In order to decide whether this extension has any bearing upon the questions now before us, the work of Jones must be consulted. Considering the probable difficulty of observing the "Diffuse" Light in the neighborhood of the Milky Way, it does not seem to me that we are warranted in attaching much significance to the location, during a single fortnight, of the small part of its southern boundary which could be laid down upon the charts.

The observations of zodiacal light at elongations of 120° or more are too few for profitable discussion in the inquiry immediately before us. In what follows, I shall assume that the zodiacal light shifts its place in latitude according to the changing position of the ecliptic in the visible hemisphere. To decide whether this change can reasonably be explained by atmospheric absorption will demand some information respecting the brightness of the zodiacal light, the relative brightness of its different parts, and the nature of the lines considered as its boundaries by different observers. No precise knowledge has yet been gained upon these subjects, but we are not entirely in ignorance with regard to them.

The general brightness of the zodiacal light has been usually estimated by comparisons made with the Milky Way. Humboldt found it equal at times to the region of Sagittarius (Hb. 126). Weber repeatedly noticed that the zodiacal light was brighter than the Milky Way, and on one occasion nearly twice as bright as its brightest portions, (1874, March 5, H. 52; see also H. 37, 40, 43, 54). Eylert makes very similar estimates (H. 47, 49). In Schmidt's general description of the light (S. 15), he says that its brighter portions, under favorable conditions for observation, exceed the mean brightness of the Milky Way. On January 26, 1848, and on March 9, 1850 (S. 31, 38,) he found the zodiacal light brighter than the brightest parts of the Milky Way. He communicated to Heis (H. 27) a more precise observation made at Athens in April, 1862, when the lower and middle part of the light appeared to be from five to six times as bright as the parts of the Milky Way at the same altitude in Argo and Cepheus. Jones occasionally describes portions of the zodiacal light as equally bright with specified regions of the Milky Way (Jj. 150, 152, 166), and remarks the simultaneous appearance of both objects, March 25, 1854 (Jj. 258). On two occasions he mentions

the superior brightness of the zodiacal light (Jj. 134, 298). The luminous arch which he afterwards observed at Quito was approximately equal to the Milky Way in brightness, but on the whole seems to have been slightly inferior to it (Jq. 377). Gruey's observations at Toulouse in February, 1875 (T. 905), make the zodiacal light about as bright as the Milky Way; sometimes a little brighter or fainter. See also the account of Lewis (Ls. 439). From all these remarks it appears pretty certain that the zodiacal light and the Milky Way are objects of the same general order of brightness, so that if the light of equal areas of their brightest portions is supposed to be concentrated at single points, the stars so formed would not differ by more than two magnitudes, and would probably differ by less than one magnitude.

The relative intensity of different parts of the zodiacal light seems not to have been investigated. We have reason to think, however, that the light fades out by degrees as it extends farther from the Sun, and also as it extends laterally from its medial line, or "axis." This appears more or less distinctly in all accounts of the phenomenon, but for the most part only indirectly, by the difficulty experienced in tracing the boundaries of the light, especially towards the vertex. An object as bright as many well-marked parts of the Milky Way, and of nearly uniform brilliancy, would of course be located without trouble. But there is also positive testimony to the same effect. Schmidt tells us (S. 15) that the light increases towards the horizon until checked by the denser strata of the atmosphere, and also mentions (S. 61) the comparative indistinctness of the vertex and the unequal intensity of different parts of the light. Jones makes a similar statement in his Introduction (Jj. xi). He also says (Jj. 346) that the "Diffuse" Light "faded away imperceptibly at its edges"; and that the "Stronger" Light "dims as it ascends." The lower portions were quite distinct on another occasion (Jj. 376) before the night had deepened sufficiently to show the remainder. The general description by Lewis (Ls. 438) confirms the preceding accounts.

The nature of the boundaries adopted by different observers apparently differs very considerably. In the case of Schmidt, we see by his account (S. 23) that the boundary is a line within the extreme limits of the light, selected as one which can be followed among the stars with a certain degree of confidence. The comparative narrowness of the light recorded by this observer, which will appear for the elongation 60° on inspection of Table I., is in conformity with the method of observation just described.

Heis and Weber probably attempt to include all the visible light within the boundaries which they adopt. This gives them a zodiacal cone wider at 60° than that of Schmidt. The "Stronger" Light of Jones is of an intermediate width; his "Diffuse" Light extends much farther than any other observer has carried the limits of the light. The form of the various cones or columns thus produced may require separate consideration at some other time; for the present, we have merely to notice the arbitrary character of the boundary. It appears to me a fair inference that the light fades away very gradually towards its edges, and this conclusion will be approved, I think, by most observers, as one accordant with their general impression of the appearance of the zodiacal light. Other occupations have always prevented me from making any careful comparisons of the kind required to decide the question; but so far as I can judge from casual observation, the light fades out as above described.

The effect produced by the zodiacal light in dimming the light of stars has apparently been seldom observed; at all events, the few results of such work which I have found on record are not sufficient to permit any inference except that the light is too faint to interfere materially with the perception of even a small star. Observations of this kind were proposed by Argelander (A. 156), but must be very numerous and frequent to make them of value.

Since the Milky Way is at present our only standard of comparison for the zodiacal light, it is desirable to form some idea of its brightness. Our chief resource must probably be the results obtained by the star-gauging observations of W. Herschel and others. The following ratios of the maximum and minimum density of the stars found in different regions of the sky appear in Celoria's discussion (C. 45): —

Uranometria Nova, Zone 0° to +6°	5.15
" " " −10° " +16°	5.29
Durchmusterung, to magn. 7.5	3.94
" " 8.0	2.90
" " 9.5	4.20
Milan observations	3.04
Herschel's gauges	62.78

The manner in which these ratios were obtained is fully explained in the work of Celoria. Although the regions considered are of limited extent in declination, they are sufficiently large to entitle the results derived from them to much confidence. The regions of maximum stellar density are well known to be in the Milky Way, and it is needless here to repeat the evidence of this fact. The Milan observa-

tions were made by Celoria with a telescope of good quality, 10 cm. in aperture, and capable of showing stars of the eleventh magnitude under favorable conditions (C. 3).

The general result is obviously that stars of medium magnitudes are much more uniformly distributed over the sky than the faint stars which make up the mass of the Milky Way, and somewhat more uniformly than the stars visible to the naked eye. From the Milan observations alone we should infer that the ratio of light from the Milky Way, in its brighter regions, to that from the darker portions of the sky, might be expressed in stellar magnitudes by about 1.2. This assumes that the average magnitude of the stars observed in the brighter and fainter regions was the same, and the assumption is probably justifiable. But with Herschel the case was very different. In the darker regions, his telescope showed no greater abundance of stars than Celoria's, while it disclosed twenty times as many in the brightest regions. It should be noted, however, that the region explored at Milan did not include the immediate neighborhood of the galactic pole. The numbers for Celoria's standard area are as follows (C. 46): —

Celoria:	maximum	15.16,	minimum	4.98.
Herschel:	"	301.16,	"	4.81.

The 286 additional stars distinguishable by Herschel's instrument in the brighter region must apparently be regarded as two or three magnitudes fainter, on the average, than the fifteen stars visible to both observers. If they were of equal magnitude with these fifteen, they would furnish nineteen twentieths of the light emitted by the region (neglecting any stars still fainter), which means that they would increase the brightness of the region by an amount to be denoted by 3.2 magnitudes. As it is, we cannot assume this increase of brightness to exceed one magnitude. Since we found the result 1.2 for the difference of magnitude between the regions of maximum and minimum density according to the Milan observations, we shall have a difference of little more than two magnitudes as the result of Herschel's observations according to Celoria's reduction.*

If the inequality of distribution among stars too faint to be separately visible to Herschel should resemble or surpass that of the fainter stars which he observed, a higher estimate of the relative brightness of the Milky Way would result. But in the absence of further information, we may perhaps make a sufficient allowance for

* See also, for confirmation, the Cape Observations of the younger Herschel, pp. 373–383.

these stars, by considering the Milky Way to be two magnitudes brighter than the mean, instead of the minimum, brightness of the sky. According to this estimate, the brightest parts of the zodiacal light may commonly be three or four magnitudes brighter than the surrounding sky. But at 60° from the Sun, it is not likely that the zodiacal light exceeds the Milky Way in brightness, and for that elongation we may suppose that its middle portions will not be more than two magnitudes brighter than the sky around it. At its assumed edges, the difference of magnitude will depend upon the choice of the observer with regard to the nature of the boundary to be employed in his observations. Suppose that he endeavors to include all the light which he can see, and that he distinguishes differences of a single tenth of a magnitude, so that, at the boundary which he adopts, the zodiacal light is brighter than the sky beyond it by one tenth of a magnitude. This may perhaps be the case with Heis and Weber (see p. 156). Taking their result of about 10° for half the extent of the light in latitude (see Table I.), we should have a variation of about one fifth of a magnitude for every degree, if we suppose the light to vary uniformly, on the scale of stellar magnitude, so as to reduce the excess of brightness from two magnitudes in the middle to one tenth of a magnitude near the boundary. If the observer, in fixing the upper and lower boundaries of the light, aims at equality of brightness in the opposite points through which he draws them, an excess of absorption at the lower edge amounting to one fifth of a magnitude will consequently set back the lower boundary about a degree. This conclusion is of no value as a representation of the true process of observation, but it indicates that the differences of atmospheric absorption required to effect a sensible displacement of the boundaries are probably not large. In this way, it appears to me to strengthen the probability that absorption is an important, and perhaps the only, cause of the variations of the zodiacal light in latitude. It may reasonably be anticipated that future observation will prove the diminution of the light from the middle towards the edges to be not uniform, but much more gradual near the edge than at some other places. In this case, the effect of absorption would at first be considerably greater than has just been supposed. But it would be useless, in the absence of direct evidence upon the subject, to adapt an imaginary gradation of light to the results obtained by observation for the displacement of the zodiacal cone. At present, we cannot even assert with confidence that the observers have aimed at equality of brightness between opposite points in the boundaries which they have drawn.

Among the facts recorded with regard to the zodiacal light is one which independently suggests the probability that the observation of the boundaries is influenced by atmospheric absorption, although it gives no information respecting the extent to which it may displace them. This fact is the customary distinctness of the lower edge as compared with the upper. It is mentioned by Schmidt in his general description of the zodiacal cone, and also later (S. 15, 27), and is repeatedly noticed by Heis and Weber (H. 4, 5, 7, 11, 16, 20, 33, 37, 39, 44, 46, 53, 57); also by Brorsen, Schmidt, and Groneman (H. 15, 27, 58). Neumayer's remark, that the southern boundary is determined with difficulty (H. 32), derives special interest from his southern station, where this boundary is the upper one. Jones has a few similar observations in the southern hemisphere (Jj. 568, 572, 586, 618), relating chiefly to the "Stronger" Light. He occasionally found the "Diffuse" Light ill defined on its lower side (Jj. 290, 330, 352). Heis, on some occasions (H. 22, 23), found that the usual comparative sharpness of the lower boundary was wanting. Lewis states as a general rule that the southern side is more sharply defined and more nearly parallel with the ecliptic (Ls. 438). He adds the interesting remark that the axis of greatest brightness lies south of the axis of symmetry. It is obvious that the increase of atmospheric absorption with zenith distance will accelerate the diminution of light near the lower side, and retard it on the other, which must have some effect in making it easier to define the lower boundary, although we could not be confident, without the support of direct observation, that the effect would be considerable enough to attract attention.

A few additional results from the tables of the Appendix acquire some significance on the hypothesis that atmospheric absorption seriously affects the observed position of the zodiacal light, but are hardly to be regarded as strengthening that hypothesis, which must rest, for the present, on the facts already set forth. The change in the "latitude of the axis" consequent upon an increase of 30° in elongation is here called "displacement," for the sake of brevity, and is considered positive when the north "latitude of the axis" increases with the elongation. This displacement has been computed only for those observations in which the position of the light was determined at each of two elongations. The number of these observations is often too small for any conclusive result, and possibly they are not worth study. But those of Jones, Heis, and Weber seem to me to be numerous enough to deserve attention. The result I find from them is that the axis of the cone, as a rule, leans towards the ecliptic, so that its lati-

tude, whether north or south, will be numerically less near the vertex than near the base. Supposing this to be an effect of atmospheric absorption, it appears that the increased brightness of the light at the smaller elongations does not fully counterbalance the increased tendency to a variation in latitude due to the increased difference in atmospheric absorption nearer the horizon. This seems antecedently probable, and indeed it may surprise us that we do not find much greater variations in latitude at small elongations. In Table II., for example, we have differences of absorption for the opposite boundaries of the "Diffuse" Light, at the elongation 60°, amounting to two or three entire magnitudes at the extreme inclinations of the ecliptic. These differences would doubtless be lessened by a strict computation, in which the position of the ecliptic would be computed separately for the same observations employed to determine the place of the light in latitude, instead of being found only for the mean of all the observations belonging to the group including them. However, in any case, the resulting differences of absorption would be large; and this would likewise be true of similar differences computed at the elongation 30°, either for the "Stronger" Light of Jones, or for the ordinary zodiacal light of other observers. Another circumstance which may seem inconsistent with the theory here advanced is, that when we compare the results at the same elongation (60°) for the "Stronger" Light in Table I. with those for the "Diffuse" Light in Table II., we find that a much smaller difference of absorption in the first case appears to produce nearly as much change of latitude. Still, the change is actually greater in the second case, and we have as yet no means of determining its theoretical value in any instance. A light which is actually confined to the zodiacal region cannot be shifted out of it by any amount of atmospheric absorption, although it may be so far diminished as to cease to be perceptible. Again, we cannot be sure, as has been said, that observers intend to signify equality of brightness on opposite sides by the location of their assumed boundaries. If the sky beyond the boundary is as much darkened as the sky within it, which may happen in the absence of haze and of artificial light in the neighborhood, the boundary might still be perceptible. Probably the condition of equality of light on the opposite sides is partially, though unconsciously, recognized in the effort to fix the boundaries, while at the same time it is not regarded as essential, especially when the boundaries are so far apart as those of the "Diffuse" Light at moderate elongations.

If atmospheric absorption has the importance here assigned to it in

the study of the zodiacal light, we cannot expect to determine the true position of the light on any occasion by the simple methods heretofore in use. We must either discover exactly what an observer means by the boundary, and to what extent this boundary will be displaced by given changes of brightness, or we must resort to direct photometric observations. The last course will probably be preferable. In the absence of instruments, observers must not content themselves with the casual comparisons heretofore made, but must compare together different portions of the light, and also specified portions of the light and of the Milky Way. The Milky Way itself must be studied in a similar manner to learn the corrections for absorption due to the varying altitude of its separate parts. Observations of this kind, it is to be apprehended, cannot be made to advantage except in situations peculiarly favorable to uniform transparency of the atmosphere at all azimuths, and remote from large towns, in order to avoid the disturbing effect of artificial light.

Perhaps some photometric apparatus may be contrived to make these determinations more generally practicable. Argelander's proposal (A. 157) to compare a portion of the zodiacal light seen with one eye and a star seen out of focus with the other, may at least furnish a suggestion for a photometer of the required kind, if it should prove inapplicable in its original form. Wolf's method (W. 32) of tracing the limits of the nebulosity about the Pleiades may likewise prove serviceable in observations of the zodiacal light. It consisted in watching the fine threads of a reticule, which became visible against the nebulosity, but disappeared when the telescope was directed to the darker sky beyond. Suppose a telescope to be provided with a series of suitable reticules, and also with some apparatus for diminishing the aperture or otherwise darkening the field. One of the most promising methods of accomplishing this object is that employed by Loewy (L. 92). A diaphragm having a circular aperture is made to slide along the tube of the telescope, and its position is recorded by means of a scale attached to the outside of the tube. If the reticules to be used are of successive degrees of fineness, so that each will be as visible with a small aperture as the next in order is with a large aperture against the same background, an extensive range of comparisons would be practicable. The same apparatus might be employed in comparing the images of stars thrown out of focus to a known extent, and a standard of comparison for faint lights might thus be established. But much experience would be needed to test the value of a photometer of this description.

Any considerable series of photometric observations of the zodiacal light, made with trustworthy apparatus and upon a suitable system, would doubtless furnish better means of determining the real position of the light with regard to the ecliptic than could be provided by the most voluminous collection of sketches. We should thus acquire some reliable information about the inclination and nodes of the great circle representing the axis of the light, which has hitherto been sought with little success. But our work, to be complete, must include an inquiry into the normal distribution of light in the sky. The zodiacal light is seen upon a background by no means of uniform brightness, even in regions remote from the Milky Way. Its more brilliant portions, very probably, may not be sensibly affected by the inequalities of the background, but its edges, and especially its vertex, cannot be determined without attention to these inequalities. The interest of a careful photometric inquiry into the relative light of different parts of the sky, and especially into the exact form of the Milky Way, would be considerable, even without reference to its bearing upon the question of the zodiacal light. But the inquiry is indispensable if we are to substitute definite knowledge for the vague information now before us with regard to "zodiacal bands," the singular phenomenon of "Gegenschein," and the possibly periodical variations in the main body of the zodiacal light, as well as its apparent changes from hour to hour.

As a first instance, let us consider the semiannual variation in the elongation of the vertex, evidence of which Serpieri has obtained from the observations of Jones (Sp. 99), confirming the result by similar data from the work of Heis (Sp. 101, H. 60). A comparison of the mean elongations for the successive months given by Serpieri, from his reduction of the work of Jones, with the corresponding series in Table XIII. of the Appendix, shows a sufficient general agreement, although there was a considerable difference between the two methods of reduction, and even in the processes by which the separate elongations were derived from the observer's charts (Sp. 62).

In both cases, we have two yearly maxima of elongation (about the beginning and middle of each calendar year) with a tolerably regular diminution and increase from each maximum to the next. The "Stronger" Light, however, shows no maximum for the evening observations of the beginning of 1854, nor, according to Serpieri, for the morning observations of the middle of 1853.

Before concluding that these variations indicate any important annual series of changes in the zodiacal light itself, we must examine

the circumstances under which the observations are necessarily made. An inspection of the charts shows us that the maxima occur at those times of year when the Milky Way cannot interfere with the observations. This is true of the eastern, as well as of the western light. We cannot very confidently assume that the interference of the Milky Way is the cause of the observed lessening in the elongations attained at other times. If it is, we must infer that, when the Milky Way intersects the zodiacal light, its brightness prevents the observer from tracing the light so far beyond it as he might in the absence of its disturbing influence. It is probable that the question must be left to the decision of photometric observations.

We may next consider the fact, hitherto resting solely on the evidence of Jones, that the apparent elongation of the zodiacal light extends as the evening advances. Most observers have contented themselves with a single drawing of the light for each date of observation, so that they give us no aid in the decision of the question. But it is highly probable that the common statements with regard to the rising and setting of the zodiacal light cannot be accepted without modification. The testimony of one industrious observer to a multitude of particular facts must ordinarily prevail over mere general assertions. Jones paid special attention at times to the mode in which the light disappeared, with varying results (Jj. 186, 190, 192, 196, 248). The darkness of the sky which he observed near the horizon, in the same stellar region where the light had been seen earlier in the evening, is certainly not conclusive, for ordinary atmospheric absorption may have produced it. On the whole, I should infer from these passages that the final disappearance of the light occurs by its setting, rather than by its fading. But this does not change the customary result, apparent everywhere in the work of Jones, that long after ordinary twilight has ended the zodiacal light continues to extend itself towards the east, contrary to the diurnal motion of the stars. I have myself noticed this phenomenon at different times, but only casually, and on occasions when no leisure for a precise record of it could be obtained. The vertex of the light seems to remain at the same altitude for a long time. Serpieri thinks that this and other results of the observations of Jones require us to abandon all purely cosmical theories of the zodiacal light, and oblige us to consider it as a terrestrial phenomenon (Sp. 73, 152). But it seems to me that before coming to this conclusion we must know more of the nature of twilight than we do now. We need to know whether the sky is really as dark just after the arch of distinct twilight has dis-

appeared as it is some hours later. General impressions and theories upon the subject should be replaced by accurate observations. If the sky grows sensibly darker for a long time after twilight, the zodiacal light may of course become more apparent during this time. Moreover, the increase of sensitiveness in the observer's eye during the evening may be more gradual than would at first be supposed.

The next class of phenomena to be discussed is that comprising the "zodiacal bands" reported by different observers. The wide zodiacal band seen by Jones at Quito (Jq. 376) need not here be considered. It is to be hoped that some equally enterprising observer will undertake the re-examination of the subject under similarly favorable conditions. At the present time, the Andes are occasionally visited by amateur mountaineers who have exhausted the Alps, and perhaps they will yet furnish us with a continuation of the interesting work which Jones considered to be in itself a sufficient object for the journey. Although he thought that traces of the band he had seen at Quito were afterwards perceptible from less advantageous stations (Jq. 378), it is certain that very few observers have seen anything approaching it in width, distinctuess, and definite position in the zodiac; and it is still to be determined whether it may not have been the effect of local or temporary causes.

The zodiacal bands more ordinarily seen have seldom been described with the exactness requisite for making satisfactory comparisons between the reports of different observers. The account given by Lewis (Ls. 441) resembles that given by Jones of his Quito observations in many important particulars. The additional facts furnished by Lewis, that the band he saw was "more sharply defined on its southern than on its northern edge," and that, "while its axis of greatest brightness is either on or very slightly north of the ecliptic, the axis of symmetry is decidedly north of that line," apparently indicate effects of atmospheric absorption. If these observations can be confirmed by others, they will have laid the foundation of an important addition to our knowledge.

So far as I have learned, only one zodiacal band has been so repeatedly and definitely described as to leave no doubt of its existence. This is a faint and narrow belt which takes a southwesterly course from the Pleiades, or rather perhaps from a place on the southern border of that group. In the Astronomische Nachrichten, XCIX. 91, 369, will be found a statement of some reasons for thinking that this band should rather be considered as a branch of the Milky Way than as especially zodiacal in its character. I am unable to trace it

through Aquarius into Capricornus. The darkness of Capricornus may certainly be due to atmospheric absorption, and observations at a more southern station are needed to decide the question. But the band, as I see it, does not terminate in Aquarius; it is continued to Aquila, quitting the zodiac altogether. This circumstance, combined with the evidence furnished by the Durchmusterung of a slight maximum of stellar density along the northern portion of the band, induces me to regard it as a sidereal and not as a zodiacal phenomenon.

The earliest account of the zodiacal portion of this band, so far as I know, was given by Schmidt, who repeatedly observed it (S. 26, 29, 32, 33, 35, 36, 44, 49, 50, 51). The definite observation of November 11, 1849 (S. 36), has a particular interest. But it can scarcely be doubted that many of the other observations refer to the same object. On October 24, 1853, the observer noticed the extension of this band into the region of α and β Aquarii (S. 44). Schmidt was in doubt about the conclusion to be drawn from these observations (S. 68), which may indicate that the explanation of them by a stream of stars had suggested itself to him; but he does not propose that hypothesis. It seems likely that his perception of the luminous band under discussion had an influence upon many of his drawings of the ordinary zodiacal light, which may partially account for the peculiarities already mentioned (p. 152).

Brorsen appears to describe this band as visible early in December, 1853 (H. 12). Later in the month, the advance of the ordinary zodiacal light tended to make it a less definite object. Groneman (H. 55) likewise describes a similar appearance on December 2, 1874. The observation made at Toulouse on November 10, 1874 (T. 1251), may perhaps relate to the same class of phenomena. Any observation of light between the Pleiades and the Milky Way, however, needs to be carefully verified by comparisons made on other occasions, for certainly there is much galactic light in that region. The prolongation beyond the Pleiades towards the southwest may belong to the band already considered. There seems to me to be an extension of the Milky Way on the opposite or eastern side, passing through and beyond Præsepe (Astr. Nachr., CII. 263), which may have had something to do with the Toulouse observation. Jones noticed this band, or part of it, on February 15, 1854 (Jj. 234). The narrow band from the Pleiades did not attract his attention, unless we suppose that it was in part the cause of the maximum of elongation which occurs, as we have seen (p. 162), about the beginning of the year. But the zodiacal light, as observed by Jones, is too wide to be readily

connected with a band only about five degrees in width, and, moreover, we might expect the maximum of elongation, if due to the perception of this band, to show itself earlier in the season. This is actually the case in the observations of Dechevrens (D. 20), who frequently noticed the band as an extension of the zodiacal light (D. 5, 10). It is natural that observers should not usually become aware of this faint object until the season of the year when it has been reached by the vertex of the ordinary zodiacal cone. In endeavoring to find the vertex, the eye then follows the previously unnoticed band as far as the Pleiades, without reaching any place at which the light can be said to terminate.

Before we can satisfy ourselves with regard to the true zodiacal bands, as they may be called, which are described by Jones and Lewis, it is necessary for us to observe accurately the extent and brightness of the similar phenomena which have just been considered. Moreover, our observations ought not to be confined to the zodiac, for, if they are, we may overlook the existence of bands of light intersecting it at considerable angles, the zodiacal portions of which may occasion perplexities in our subsequent work. The need of general knowledge with respect to the normal distribution of light in the sky thus becomes evident, even if we seek only a thorough knowledge of zodiacal phenomena.

Admitting the occurrence of the phenomenon called "Gegenschein," which certainly has a large mass of evidence in its favor, we must still feel much uncertainty about its visibility on particular occasions, until we are able to say with some confidence that the light we are observing is greater than the normal light of the region in which it appears. At present, we have only our memory of former observations to prevent mistakes, and if the observer feels sure of the correctness of his own memory, he ought to have some surer means of making the facts of the case clear to others who have not witnessed them. For the study of all zodiacal phenomena, therefore, a photometric survey of the sky is urgently required.

Although the opinion of Serpieri, that the zodiacal light is a species of aurora (Sp. 153), will probably not find general acceptance in the present state of our knowledge, it is likely that auroral and zodiacal light may sometimes be confounded with each other. Auroral bands sometimes occur, as is well known, in the form of arches extending from the eastern to the western horizon, and retaining their form and place for a considerable time. It is possible that such arches are formed at times in the absence of any other auroral light. If this

should happen at a time when the azimuth of the pole of the ecliptic is approximately equal to the magnetic declination, we might have an auroral band along the zodiac which would be taken for zodiacal light. It is mainly for this reason that it has seemed desirable to provide in the Appendix for approximate determinations of the azimuth of the pole of the ecliptic.

Eylert's observations of December 8 and 9, 1873 (H. 49, 50), afford instances where the presence of auroral light may be suspected. On these dates he saw a luminous arch crossing the heavens, the western part of which had the customary form and position of zodiacal light; but the eastern part made an angle of about 17° with the ecliptic, from which it deviated to the southeast. The observer was in latitude about +20°, longitude about 30° west of Greenwich, where the magnetic declination is about 15° west. The azimuth of the north pole of the ecliptic was about 23° west of north, and its zenith distance about 76° for the mean of the two observations. It follows that the aberrant portion of the zodiacal light was more nearly perpendicular to the magnetic meridian than to the circles of latitude, but the deviation was in excess of what would be required on the hypothesis that an auroral band was seen. It may not be always the case that these auroral bands are perpendicular to the magnetic meridian, and the evidence of auroral light in this instance is not at all conclusive.

A few days later, on the evening of December 12, 1873, Serpieri, at Urbino in Italy, observed a general illumination of the zodiac (H. 51). The occurrence of coruscations in the light on this occasion perhaps adds a little weight to the suspicion of auroral action, but these coruscations, or pulsations, as Jones called them, have often been seen in the zodiacal light proper. The nature of this phenomenon, also, evidently requires photometric investigation. On the evening of January 31, 1883, I found, during half an hour's observation, that there were apparent variations in the relative brightness of definite portions of the zodiacal light with respect to definite portions of the Milky Way. But the variation may not have been real, or it may possibly have been due to variable haze, too indefinite in outline to be recognized.

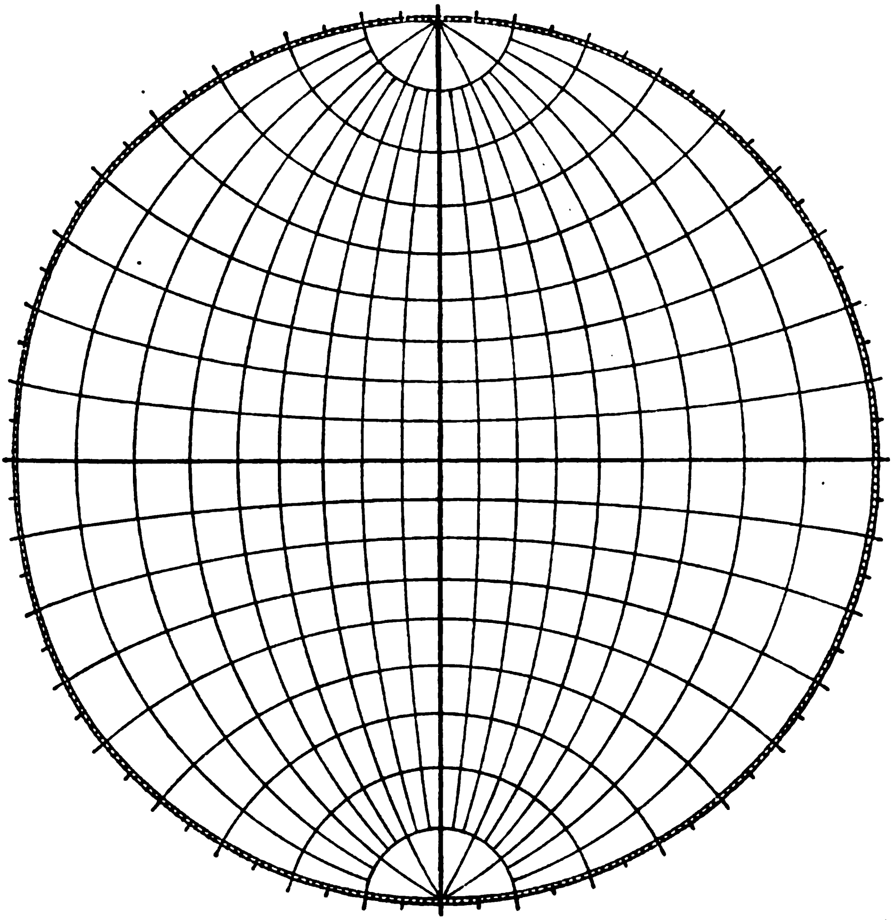
It is not my intention, on this occasion, to discuss the probability of any explanation of the zodiacal light. I have merely to remark, with regard to the ordinary meteoric theory, that it gains greatly in simplicity if we dispense with all the imaginary meteoric bodies or rings with which it has usually been connected, and retain merely the conception of meteoric dust diffused throughout the Solar System. It may

be shown mathematically, if we regard the meteoric particles as solids, reflecting light irregularly, that an appearance like the zodiacal cone, with an indefinite vertex, would result. On this subject, the work of Geelmuyden may be consulted (G. 95, 106).

APPENDIX.

In passing from one system of spherical co-ordinates to another, an approximate result is sometimes all that is required. This is usually the case when the zodiacal light is the subject under consideration, and occasionally happens in the course of other inquiries; for example, during the computation of differential refraction, or when it is desirable to know that no gross error has occurred in the computation of an exact position. For all such purposes, the projection of a hemisphere with the poles upon the circumference is a convenient resource. A stereographic projection, like that given in the annexed figure, has the advantage of being very easily constructed, at least when the scale is small, but any circular and symmetrical chart of a hemisphere will suffice. It is needless to state the principles of this method of changing co-ordinates, but a few illustrations of its use may be serviceable. In the following directions, a piece of tracing paper is supposed to be at hand, but it may obviously be replaced by measurements from the centre and from the proper points on the circumference of the chart. Although the figure here given is a somewhat distorted copy of the drawing which it represents, it will probably be found sufficiently accurate to be of some use.

In discussing observations of the zodiacal light, we may require the zenith distances, and perhaps the azimuths of a number of points the latitudes and longitudes of which are known, while we also have the latitude and longitude of the zenith, and the azimuth of one pole of the ecliptic. In this case, consider the circumference of the projection as representing the circle of latitude passing through the zenith. Begin by regarding the chart as one exhibiting latitudes and longitudes. Mark the centre of the projection upon the tracing paper, and lay down the place of the zenith, by means of its latitude, upon either side of the circumference, as may be preferred. Knowing the longitude of the zenith, we can also lay down the place of the Sun and those of the required points, or we can make a sketch of the zodiacal light as defined by elongation and latitude. Then turn the paper so that



the point marked as the zenith may coincide with the proper pole of the projection, keeping the point marked as the centre in position. The co-ordinates of the chart will now be altitude and azimuth, in terms of which we may read off the new positions of the points previously laid down in latitude and longitude. The origin of the azimuth readings is to be obtained from the known azimuth of the pole of the ecliptic. It will rarely happen that any of the required points will lie in the hemisphere opposite to that supposed to be exhibited on the chart, but if this should be the case, these points can be laid down as easily as the others, from which they may be distinguished by a special form of marking, in order to prevent errors in reading their co-ordinates after the paper has been turned.

If we desire to convert right ascensions and declinations into equivalent positions in latitude and longitude, we regard the circumference of the projection as the solstitial colure. After marking the required points upon the tracing paper, we turn it through an angle equal to the obliquity of the ecliptic, and read off the new positions of the marks. As the right ascension and declination of the zenith are known from the sidereal time and terrestrial latitude, this method may be used to obtain the celestial latitude and longitude of the zenith, which were supposed to be known in the former example. If the azimuth of the pole of the ecliptic is required, we may suppose the circumference of the projection to represent the meridian, lay down the pole of the ecliptic on the tracing paper, and turn it through an angle equal to the complement of the terrestrial latitude. But the relative positions of the zenith and ecliptic may generally be found still more readily from the tables given below, with sufficient accuracy for many purposes.

The chart may be used conveniently for determining zenith distances and parallactic angles in a given terrestrial latitude by first drawing the given parallel of latitude on the tracing paper, marking its intersections with the meridians, and numbering these intersections. The centre of the projection, and the pole, are likewise to be marked, as in other cases. If the circumference of the projection is then regarded as the circle of declination passing through a known star, we may set the point marked as the pole to the place of this star, read its hour angle along the traced parallel of latitude, and the corresponding zenith distance and parallactic angle by the co-ordinates of the chart at the point of the parallel thus determined. The azimuth of the star may then be found, if desired, by supposing the triangle inverted, so that the zenith distance will be read along the circumference. After turning the paper to the corresponding position, the azimuth can be read off on the traced parallel.

In general, a chart of this form may be used for the solution of any spherical triangle, two sides of which, with the included angle, are given. The drawing might be constructed on a scale large enough to read tenths of a degree with considerable accuracy, and a sheet of slightly ground glass or of transparent parchment might be permanently centred over it to make its use more expeditious and precise. It may sometimes be worth while to take the mean of results obtained in different quadrants. With the help of two traced parallels, indicating respectively the declinations of the pole of the ecliptic and of the zenith, the chart may be applied to the solution of various problems in which the three sides of a triangle are known.

The time of an observation of the zodiacal light is seldom recorded with precision. Even if it were possible to fix the time of such an observation accurately, there is as yet no apparent advantage in attempting to do so, except when rapid changes seem to be occurring in the brightness and extent of the light. It is consequently superfluous to make any exact determination of the position of the ecliptic in the visible hemisphere at the time of each observation. In such computations of the kind as are required, we may disregard the changes in the relation between mean and sidereal time, at given dates and places, due to the occurrence of leap year, to the gain of the sidereal clock during a single day, and to the longitude of the observer. Tables III. to IX. inclusive (pp. 179–184) give the approximate position of the ecliptic for any date and any mean time. They have been employed in the formation of the subsequent tables, but are given here in a modified form for the sake of convenience in printing, which may occasionally make a slight change in single results derived from them. Table III. gives the approximate longitude of the Sun for the first day of each month, and the hour angle of the north pole of the ecliptic for each hour of mean time on the same days. This hour angle is counted towards the west, from 0° to 360°. Interpolation in this table is effected without trouble by allowing one degree a day for a change in date, and fifteen degrees an hour for a change in time. With the hour angle thus obtained for one argument, and the latitude of the observer's station for another, Tables IV. to IX. inclusive give the zenith distance of the north pole of the ecliptic, the azimuth of the same pole, counted from north to west and from 0° to 360°, and the longitude of the zenith. Each of these tables is divided into two parts by a heavy rule between the latitudes 60° and 70°, to show that interpolation is subject to some inconvenience at these places, on account of the passage of the pole of the ecliptic. This part of the tables,

however, will seldom be consulted in any use to which they are put, and probably never in discussing observations of the zodiacal light. From the longitude of the zenith derived from these tables, the longitude of the Sun (from Table III.) is to be subtracted when the "elongation of the zenith" is required for an evening observation.

Table X. contains the results of measurements made upon the charts representing the evening observations published by Jones in his large work referred to in the preceding discussion as "Jj." The numbers in the first column refer to the charts employed. The date in the second column, and the latitude in the fourth, are also taken from Jones, south latitudes being here expressed in Italic figures. The longitude of the Sun in the third column, and the quantity *t* in the fifth (*t* signifying the hour angle of the north pole of the ecliptic), are taken from Table III., with the aid of the times of observation recorded by Jones, which can accordingly be approximately reproduced by means of Table III., in case they are desired by any reader who cannot consult the original work. These data are followed by two columns giving the respective elongations of the vertices of the "Stronger" and "Diffuse" Lights observed by Jones. These elongations were measured from the place of the Sun as given on most of the observer's published charts. In some cases, this place falls beyond the limits of the chart, and Jones then adds a note giving the longitude of the Sun which was employed in the measurement. The next six columns contain the north and south latitudes of the boundary of the "Stronger" Light at the respective elongations 30°, 60°, and 90°. These elongations were found upon the charts in the same way as those of the vertex. When the northern boundary lies south of the ecliptic, or the southern boundary north, the measured latitude is regarded as negative, and is expressed in Italic figures, which are used throughout these tables as a substitute for the negative sign. The last six columns give the corresponding figures for the "Diffuse" Light at the elongations 60°, 90°, and 120°. All the measurements made upon the charts were merely approximate, and they have not, in general, been revised. They are believed, however, to have been made with sufficient care for the purpose in view. When the boundaries drawn upon the chart terminated near the longitude at which the measurement was to be made, they were occasionally extended by estimate in order to obtain a latitude, but the number of these estimates forms a very small proportion of the entire number of entries. When an unusually large number of observations were made upon a single evening (as on occasions when "pulsations" in

the light were noticed), some of them are often omitted in Table X. A few accidental omissions may also have occurred.

Table XI. contains results similar to those of Table X., taken from the Zodiacallicht-Beobachtungen of Heis, to which reference is made in the preceding discussion by the letter H. The first column of Table XI. contains a continuous series of numbers, not taken from Heis, but inserted here for convenience of reference. The second column gives the name of the observer, and the third the date. The next three columns give the longitude of the Sun, the latitude of the observer, and the hour angle of the north pole of the ecliptic, denoted by t, as in Table X., and found in the same manner. These columns are followed by the elongation of the vertex, which is occasionally given by Heis in half-degrees, but here expressed in whole degrees only. The last six columns give the latitudes of the northern and southern boundaries at the elongations 30°, 60°, and 90°, as in the case of the "Stronger" Light of Jones. In the work of Heis, the latitudes of the northern and southern boundaries are given at intervals of 10° in longitude. The longitude of the vertex, as well as its elongation, is also given. From these data the latitudes of Table XI. have been obtained by estimate. Negative quantities are expressed by Italic figures, as already explained in the description of Table X.

Table XII. contains results derived from Schmidt's work, "Das Zodiacallicht," designated as "S" in the preceding discussion. The observations are here arranged in the order of the seasons, as they were placed by Schmidt on pages 55–61 of his work. Besides the observations there given, five others, made Dec. 1–20, have been collected from the previous pages. Schmidt seems to regard them as too uncertain to be worth reduction (S. 54, 68), but it has been shown above (p. 165) that they probably have a distinct meaning.

The first three columns of Table XII. contain a number for reference, the date of the observation, and the latitude of the observer's station. The next four columns give the zenith distance of the north pole of the ecliptic (here called the inclination of the ecliptic for the sake of brevity), the azimuth of the north pole of the ecliptic, the longitude of the Sun, and the elongation of the zenith, all derived from Tables III. to IX. inclusive. The last ten columns give the north and south latitudes of the boundary of the light for the elongations 30°, 60°, 90, 120°, and 150°. They are derived from Schmidt's data on pages 55–61 of his work, except that for the first five observations a separate reduction was necessary. This was effected by means of a chart like that just explained (p. 168).

Tables XIII. to XVIII. inclusive contain monthly means derived from Table X. In order to facilitate any grouping of the months which may appear desirable, the sums of the readings have generally been retained in these tables, the form of which, in other respects, has been largely determined by considerations of convenience in printing. Table XIII. gives the names of the successive months during which Jones carried on his work, preceded by a column of numbers for reference, which is repeated in the subsequent tables without the names of the corresponding months. The third column of Table XIII. gives the number of evenings in each month on which the observations collected in Table X. were made, and in the fourth column are entered the corresponding total numbers of observations. The fifth column gives the mean result for the observer's latitude, expressed in whole degrees. The next two columns contain the inclination of the ecliptic and the azimuth of its north pole, as in the corresponding columns of Table XII. Instead, however, of finding these quantities for each separate observation and taking their means, it was considered sufficient to take the monthly means of the quantities in column *t* of Table X., and to combine the result with the mean latitude. The mean of the longitudes of the Sun for each month is given in the next column, and this is followed by the elongation of the zenith, the longitude of which was first found from the mean values of *t* and the observer's latitude, as just explained. The last six columns of Table XIII. give the mean elongations of the vertices of the "Stronger" and "Diffuse" Lights, preceded by the numbers of observations and the sums from which the means were derived.

Tables XIV. and XV. give in like manner, for the "Stronger" and "Diffuse" Lights respectively, the mean latitudes of their northern and southern boundaries at the various elongations included in Table X., with the numbers and sums used in obtaining the means.

Tables XVI. and XVII. give mean results at the same elongations for the "latitude of the axis" (as we may call the mean of the latitudes of the northern and southern boundaries), and for half the extent of the light in latitude (the "halbe Dicke" of Schmidt). Italic figures here indicate south latitudes. In obtaining these results, only those observations of Table X. were employed in which both the northern and the southern boundaries had been observed at the required elongations. The results accordingly differ to some extent from those which would be obtained by the combination of the mean results given in Tables XIV. and XV.

Table XVIII. gives the mean results for the changes produced in

the "latitude of the axis" and the "half extent in latitude" just explained, by an increase of thirty degrees in the elongation. Here also only those observations have been used which afforded complete determinations, and the results will differ from those directly obtainable by comparison of the quantities found in Tables XVI. and XVII. This restriction of the observations, of course, often makes the number which can be used too small to permit any inference from the result until it has been combined with others to form a larger group. The data of Table XVIII. are given under the headings "Displacement" and "Contraction," respectively, for stated changes of elongation. Under "Displacement," the negative results expressed by Italic figures indicate that the axis lies farther south at the greater elongation. Under "Contraction," the diminution of the "half extent in latitude" is expressed as a positive quantity, and a negative result would mean that this extent increased, instead of diminishing, with the elongation.

In discussing the observations of Table XI., those made by Eylert and by Neumayer, owing to their small number, can be reduced separately with little trouble. It seemed best, however, to furnish an intermediate step in the reduction of those made by Heis and Weber, (as has already been done for those of Jones by Tables XIII. to XVIII. inclusive). They have accordingly been arranged according to the calendar months, and the mean results thus obtained are given in Tables XIX. to XXII. inclusive. The form of Table XIX. is nearly the same as that of Table XIII. As only one observation was made on a single day, the column "No. of Days" is omitted; and the column of months does not proceed in chronological order, as in Table XIII., but combines the observations of different years. Since Heis and Weber sometimes observed an "inner cone," the mean elongation of its vertex is here given in a space which would otherwise be vacant; the separate observations are too few to require a place in Table XI. Table XX. gives for Heis and Weber results corresponding to those of Tables XIV. and XV. for Jones. Tables XXI. and XXII. in like manner correspond to Tables XVI., XVII., and XVIII., with one difference. From the form in which Heis gives the observations, it is sometimes practicable to find the latitude of the axis at elongations for which the latitudes of the boundaries cannot so well be estimated. This allows the number of observations of the axis, in Table XXI., occasionally to exceed that of the observations of "half extent." Similarly, in Table XXII., the numbers for "Displacement" and for "Contraction" sometimes differ, and are therefore given in separate columns, instead of together, as in Table XVIII.

The remaining tables exhibit a grouping of the observations according to the principle announced by Jones that the position of the zodiacal light in latitude differs according to the inclination of the ecliptic, as it has been called in the previous tables; that is, according to the zenith distance of the north pole of the ecliptic. Tables XXIII. to XXVI. inclusive arrange the results here obtained for the work of Jones in seven groups defined as follows: Group 1 includes the observations of 1853, June, July, August, and September; and of 1854, May, June, July, September, and October. Group 2 includes 1853, October, and 1854, August and November. Group 3 includes 1854, April and December. Group 4 includes 1853, November and December; 1854, February and March; 1855, April. Group 5 includes 1853, April, and 1854, January. Group 6 includes only 1855, January, and Group 7, 1855, February and March. The numbers of these groups are given in the first column of each table from XXIII. to XXVI. inclusive. In Table XXIII. the second and third columns give the mean inclination of the ecliptic and elongation of the zenith derived from Table XIII., allowing equal weight to all the separate observations, so that the weight allowed to the result for each month is proportional to the number of observations for that month. The next two columns give the number of observations of the elongation of the vertex of the "Stronger" Light, with the mean result, allowing all observations equal weight, as before. The remainder of the table contains the mean results for the latitude of the boundaries of the "Stronger" Light, with the number of observations on which each depends, collected from Table XIV.

Table XXIV. contains similar data for the "Diffuse" Light, from Tables XIII. and XV. In the second and third columns, instead of repeating the inclination and elongation already given in Table XXIII., it appeared more convenient to insert the mean latitude of the observer, and the zenith distance of the Sun, this last being derived from the data of Table XXIII. by means of a chart.

Tables XXV. and XXVI. give for each of the seven groups, and for the "Stronger" and "Diffuse" Lights respectively, the number of observations and the mean result for "latitude of axis," "half extent in latitude," "displacement," and "contraction," as already explained. These quantities are obtained from Tables XVI., XVII., and XVIII.

Tables XXVII. and XXVIII. contain a similar series of results for the work of Heis and Weber. The groups, for Heis, are as follows: Group 1, May, November, December; Group 2, January, April; Group 3, February, March. The two observations, one in

July and one in August, are here neglected. For Weber, Group 1 comprises May and December; Group 2, January and April; Group 3, February and March. The form of Table XXVII. is the same as that of Table XXIII.; while Table XXVIII. resembles Table XXV., but gives the number of observations separately for "axis" and "extent," for "displacement" and "contraction." The reason for this has already been given in describing Tables XXI. and XXII.

Tables XXIX. to XXXII. inclusive refer to the observations of Eylert and Neumayer, combined in a single grouping, since Neumayer's four observations are not sufficient for a separate discussion. The groups are as follows: Group 1 contains the observations numbered 273, 274, 290, 291, 292, in Table XI.; Group 2 contains Nos. 287, 288, 289; Group 3, Nos. 275, 276, 277, 285, 286, 295, 296; Group 4, Nos. 278 to 284 inclusive, and Nos. 293, 294. The form of Table XXIX. agrees with that of Table XXIII. Table XXX. contains a few means from observations not detailed in Table XI. for want of space. These include four observations of the elongation of the vertex of an "inner cone," and four observations of the boundaries at elongations greater than 90°. The second and third columns of Table XXX. are filled by the latitude of the observer according to the mean of all the observations belonging to the group, and by the zenith distance of the Sun from the data in the second and third columns of Table XXIX. The form of Table XXXI. is that of Table XXV., and Table XXXII. gives similar data for the observations at extreme elongations just mentioned.

In Tables XXXIII. and XXXIV. the observations of Table XII. are grouped as follows: Group 1 contains Nos. 1, 2, 8, 11; Group 2, Nos. 3, 4, 5, 6, 7, 9, 10, 12, 32, 33, 37; Group 3, Nos. 13 to 25 inclusive, and Nos. 28, 36; Group 4, Nos. 26, 27, 29, 30, 31, 34, 35. Table XXXIII. has nearly the form of Table XXIII., with the addition of a section for observations at the elongation 120°. The second and fifth columns give the latitude of the observer and the zenith distance of the Sun; while the third and fourth give the inclination of the ecliptic and the elongation of the zenith. Table XXXIV. gives data corresponding to those of Table XXV., but extending, as in Table XXXIII., to the elongation 120°.

Table XXXV. gives the relative amount of atmospheric absorption, expressed in terms of stellar magnitude, for different zenith distances. It is derived from Müller's table (p. 59 of his Photometrische Untersuchungen). At zenith distances less than 17°, the absorption is less than five thousandths of a magnitude in excess of its value at the zenith.

TABLE III. — Hour Angle of North Pole of Ecliptic.

Date.	Jan. 1	Feb. 1	Mar. 1	April 1	May 1	June 1	July 1	Aug. 1	Sept 1	Oct. 1	Nov. 1	Dec. 1
Long. of Sun.	281°	312°	340°	11°	40°	70°	99°	129°	158°	188°	219°	249°
Mean Time. h	°	°	°	°	°	°	°	°	°	°	°	°
0	11	41	69	100	129	160	190	220	251	280	311	340
1	26	56	84	115	144	175	205	235	266	295	326	355
2	41	71	99	130	159	190	220	250	281	310	341	10
3	56	86	114	145	174	205	235	265	296	325	356	25
4	71	101	129	160	189	220	250	280	311	340	11	40
5	86	116	144	175	204	235	265	295	326	355	26	55
6	101	131	159	190	219	250	280	310	341	10	41	70
7	116	146	174	205	234	265	295	325	356	25	56	85
8	131	161	189	220	249	280	310	340	11	40	71	100
9	146	176	204	235	264	295	325	355	26	55	86	115
10	161	191	219	250	279	310	340	10	41	70	101	130
11	176	206	234	265	294	325	355	25	56	85	116	145
12	191	221	249	280	309	340	10	40	71	100	131	160
13	206	236	264	295	324	355	25	55	86	115	146	175
14	221	251	279	310	339	10	40	70	101	130	161	190
15	236	266	294	325	354	25	55	85	116	145	176	205
16	251	281	309	340	9	40	70	100	131	160	191	220
17	266	296	324	355	24	55	85	115	146	175	206	235
18	281	311	339	10	39	70	100	130	161	190	221	250
19	296	326	354	25	54	85	115	145	176	205	236	265
20	311	341	9	40	69	100	130	160	191	220	251	280
21	326	356	24	55	84	115	145	175	206	235	266	295
22	341	11	39	70	99	130	160	190	221	250	281	310
23	356	26	54	85	114	145	175	205	236	265	296	325

TABLE IV. — Zenith Distance of North Pole of Ecliptic.

For Stations in North Latitude.

North lat.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	North lat.
Hour angle of north pole of ecliptic. ° 0	° 67	° 57	° 47	° 37	° 27	° 17	° 7	° 3	° 13	° 23	° 0 Hour angle of north pole of ecliptic.
10	67	57	47	37	27	17	8	5	14	23	350
20	68	58	48	38	29	19	11	8	14	23	340
30	70	60	50	41	31	22	15	11	16	23	330
40	72	63	53	44	35	26	19	15	17	23	320
50	75	66	56	47	38	30	23	18	19	23	310
60	79	69	60	51	42	34	27	22	20	23	300
70	82	73	64	55	46	38	30	25	22	23	290
80	86	77	68	59	50	42	34	28	24	23	280
90	90	81	72	63	54	45	37	30	25	23	270
100	94	85	76	66	58	49	41	33	27	23	260
110	98	89	79	70	61	52	43	35	28	23	250
120	101	92	83	73	64	55	46	37	30	23	240
130	105	95	86	76	67	57	48	39	31	23	230
140	108	98	88	79	69	60	50	41	32	23	220
150	110	100	91	81	71	61	52	42	32	23	210
160	112	102	92	82	72	62	53	43	33	23	200
170	113	103	93	83	73	63	53	43	33	23	190
180	113	103	93	83	73	63	53	43	33	23	180
North lat.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	North lat.

TABLE V. — Azimuth of North Pole of Ecliptic, from North through West.

For Stations in North Latitude.

North lat.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	North lat.
Hour angle of north pole of ecliptic.											Hour angle of north pole of ecliptic.
0°	0°	0°	0°	0°	0°	0°	0°	180°	180°	180°	0°
10	4	5	5	7	9	13	30	128	163	170	10
20	8	9	11	13	16	24	45	106	147	160	20
30	12	13	15	18	22	31	51	93	132	150	30
40	16	17	19	22	27	36	53	84	119	140	40
50	18	20	21	25	30	38	52	76	107	130	50
60	21	22	24	26	31	38	50	70	96	120	60
70	22	23	25	27	31	38	48	64	86	110	70
80	23	24	25	27	31	36	45	58	77	100	80
90	23	24	25	27	30	34	41	52	68	90	90
100	23	23	24	25	28	31	37	46	60	80	100
110	22	22	22	23	25	28	33	40	52	70	110
120	21	20	20	21	23	25	29	35	44	60	120
130	18	18	18	18	19	21	24	29	37	50	130
140	16	15	15	15	16	17	19	23	29	40	140
150	12	12	11	12	12	13	15	17	22	30	150
160	8	8	8	8	8	9	10	12	14	20	160
170	4	4	4	4	4	4	5	6	7	10	170
180	0	0	0	0	0	0	0	0	0	0	180
190	356	356	356	356	356	356	355	354	353	350	190
200	352	352	352	352	352	351	350	348	346	340	200
210	348	348	349	348	348	347	345	343	338	330	210
220	344	345	345	345	344	343	341	337	331	320	220
230	342	342	342	342	341	339	336	331	328	310	230
240	339	340	340	339	337	335	331	325	316	300	240
250	338	338	338	337	335	332	327	320	308	290	250
260	337	337	336	335	332	329	328	314	300	280	260
270	337	336	335	333	330	326	319	308	292	270	270
280	337	336	335	333	329	324	315	302	283	260	280
290	338	337	335	333	329	322	312	296	274	250	290
300	339	338	336	334	329	322	310	290	264	240	300
310	342	340	339	335	330	322	308	284	253	230	310
320	344	343	341	338	333	324	307	276	241	220	320
330	348	347	345	342	338	329	309	267	228	210	330
340	352	351	349	347	344	336	315	254	213	200	340
350	356	355	355	353	351	347	330	232	197	190	350
0	0	0	0	0	0	0	0	180	180	180	0
North lat.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	North lat.

TABLE VI.—Longitude of Zenith.

For Stations in North Latitude.

North lat.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	North lat.
Hour angle of north pole of ecliptic.											Hour angle of north pole of ecliptic.
0°	270°	270°	270°	270°	270°	270°	270°	90°	90°	90°	0°
10	281	282	283	284	287	293	304	48	83	90	10
20	292	293	296	298	303	311	333	36	76	90	20
30	302	305	308	312	317	327	348	31	71	90	30
40	312	315	319	324	330	340	359	31	68	90	40
50	322	326	330	335	342	351	8	33	65	90	50
60	332	336	340	345	352	1	15	36	64	90	60
70	342	345	350	355	1	10	22	40	64	90	70
80	351	355	359	4	10	18	28	43	65	90	80
90	0	4	8	13	18	25	35	48	66	90	90
100	10	13	17	22	27	33	41	52	68	90	100
110	19	22	26	30	35	40	47	56	70	90	110
120	28	31	35	38	42	47	53	61	72	90	120
130	38	41	44	47	50	54	59	66	75	90	130
140	48	50	53	55	58	61	65	70	78	90	140
150	58	60	62	64	66	68	71	75	81	90	150
160	68	70	71	73	74	76	78	80	84	90	160
170	79	80	81	81	82	83	84	85	87	90	170
180	90	90	90	90	90	90	90	90	90	90	180
190	101	100	99	99	98	97	96	95	93	90	190
200	112	110	109	107	106	104	102	100	96	90	200
210	122	120	118	116	114	112	109	105	99	90	210
220	132	130	127	125	122	119	115	110	102	90	220
230	142	139	136	133	130	126	121	114	105	90	230
240	152	149	145	142	138	133	127	119	108	90	240
250	161	158	154	150	145	140	133	124	110	90	250
260	170	167	163	158	153	147	139	128	112	90	260
270	180	176	172	167	162	155	145	132	114	90	270
280	189	185	181	176	170	162	152	137	115	90	280
290	198	195	190	185	179	170	158	140	116	90	290
300	208	204	200	195	188	179	165	144	116	90	300
310	218	214	210	205	198	189	172	147	115	90	310
320	228	225	221	216	210	200	181	149	112	90	320
330	238	235	232	228	223	213	192	149	109	90	330
340	248	247	244	242	237	229	207	144	104	90	340
350	259	258	257	256	253	247	236	132	97	90	350
0	270	270	270	270	270	270	270	90	90	90	0
North lat.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	North lat.

TABLE VII. — ZENITH DISTANCE OF NORTH POLE OF ECLIPTIC.

For Stations in South Latitude.

South lat.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	South lat.
Hour angle of north pole of ecliptic.											Hour angle of north pole of ecliptic.
0°	67°	77°	87°	97°	107°	117°	127°	137°	147°	157°	0°
10	67	77	87	97	107	117	127	137	147	157	350
20	68	78	88	98	108	118	127	137	147	157	340
30	70	80	89	99	109	119	128	138	148	157	330
40	72	82	92	101	111	120	130	139	148	157	320
50	75	85	94	104	113	123	132	141	149	157	310
60	79	88	97	107	116	125	134	143	150	157	300
70	82	91	101	110	119	128	137	145	152	157	290
80	86	95	104	114	122	131	139	147	153	157	280
90	90	99	108	117	126	135	143	150	155	157	270
100	94	103	112	121	130	138	146	152	156	157	260
110	98	107	116	125	134	142	150	155	158	157	250
120	101	111	120	129	138	146	153	158	160	157	240
130	105	114	124	133	142	150	157	162	161	157	230
140	108	117	127	136	145	154	161	165	163	157	220
150	110	120	130	139	149	158	165	169	164	157	210
160	112	122	132	142	151	161	169	172	166	157	200
170	113	123	133	143	153	163	172	175	166	157	190
180	113	123	133	143	153	163	178	177	167	157	180
South lat.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	South lat.

TABLE VIII. — Azimuth of North Pole of Ecliptic, from North through West.

For Stations in South Latitude.

South lat.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	South lat.
Hour angle of north pole of ecliptic.											Hour angle of north pole of ecliptic.
0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°
10	4	4	4	4	4	4	5	6	7	10	10
20	8	8	8	8	8	9	10	12	14	20	20
30	12	12	11	12	12	13	15	17	22	30	30
40	16	15	15	15	16	17	19	23	29	40	40
50	18	18	18	18	19	21	24	29	37	50	50
60	21	20	20	21	23	25	29	35	44	60	60
70	22	22	22	23	25	28	33	40	52	70	70
80	23	23	24	25	28	31	37	46	60	80	80
90	23	24	25	27	30	34	41	52	68	90	90
100	23	24	25	27	31	36	45	58	77	100	100
110	22	23	25	27	31	38	48	64	86	110	110
120	21	22	24	26	31	38	50	70	96	120	120
130	18	20	21	25	30	38	52	76	107	130	130
140	16	17	19	22	27	36	53	84	119	140	140
150	12	13	15	18	22	31	51	93	132	150	150
160	8	9	11	13	16	24	45	106	147	160	160
170	4	5	5	7	9	13	30	128	163	170	170
180	0	0	0	0	0	0	0	180	180	180	180
190	356	355	355	353	351	347	330	232	197	190	190
200	352	351	349	347	344	336	315	254	213	200	200
210	348	347	345	342	338	329	309	267	228	210	210
220	344	343	341	338	333	324	307	276	241	220	220
230	342	340	339	335	330	322	308	284	253	230	230
240	339	338	336	334	329	322	310	290	264	240	240
250	338	337	335	333	329	322	312	296	274	250	250
260	337	336	335	333	329	324	315	302	283	260	260
270	337	336	335	333	330	326	319	308	292	270	270
280	337	337	336	335	332	329	323	314	300	280	280
290	338	338	338	337	335	332	327	320	308	290	290
300	339	340	340	339	337	335	331	325	316	300	300
310	342	342	342	342	341	339	336	331	323	310	310
320	344	345	345	345	344	343	341	337	331	320	320
330	348	348	349	348	348	347	345	343	338	330	330
340	352	352	352	352	352	351	350	348	346	340	340
350	356	356	356	356	356	356	355	354	353	350	350
0	0	0	0	0	0	0	0	0	0	0	0
South lat.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	South lat.

TABLE IX. — Longitude of Zenith.

For Stations in South Latitude.

Hour angle of north pole of ecliptic. South lat.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	Hour angle of north pole of ecliptic. South lat.
0°	270°	270°	270°	270°	270°	270°	270°	270°	270°	270°	0°
10	281	280	279	279	278	277	276	275	273	270	10
20	292	290	289	287	286	284	282	280	276	270	20
30	302	300	298	296	294	292	289	285	279	270	30
40	312	310	307	305	302	299	295	290	282	270	40
50	322	319	316	313	310	306	301	294	285	270	50
60	332	329	325	322	318	313	307	299	288	270	60
70	342	338	334	330	325	320	313	304	290	270	70
80	351	347	343	338	333	327	319	308	292	270	80
90	0	356	352	347	342	335	325	312	294	270	90
100	10	5	1	356	350	342	332	317	295	270	100
110	19	15	10	5	359	350	338	320	296	270	110
120	28	24	20	15	8	359	345	324	296	270	120
130	38	34	30	25	18	9	352	327	295	270	130
140	48	45	41	36	30	20	1	329	292	270	140
150	58	55	52	48	43	33	12	329	289	270	150
160	68	67	64	62	57	49	27	324	284	270	160
170	79	78	77	76	73	67	56	312	277	270	170
180	90	90	90	90	90	90	90	270	270	270	180
190	101	102	103	104	107	113	124	228	263	270	190
200	112	113	116	118	123	131	153	216	256	270	200
210	122	125	128	132	137	147	168	211	251	270	210
220	132	135	139	144	150	160	179	211	248	270	220
230	142	146	150	155	162	171	188	213	245	270	230
240	152	156	160	165	172	181	195	216	244	270	240
250	161	165	170	175	181	190	202	220	244	270	250
260	170	175	179	184	190	198	208	223	245	270	260
270	180	184	188	193	198	205	215	228	246	270	270
280	189	193	197	202	207	213	221	232	248	270	280
290	198	202	206	210	215	220	227	236	250	270	290
300	208	211	215	218	222	227	233	241	252	270	300
310	218	221	224	227	230	234	239	246	255	270	310
320	228	230	233	235	238	241	245	250	258	270	320
330	238	240	242	244	246	248	251	255	261	270	330
340	248	250	251	253	254	256	258	260	264	270	340
350	259	260	261	261	262	263	264	265	267	270	350
0	270	270	270	270	270	270	270	270	270	270	0
South lat.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	South lat.

TABLE X.—EVENING OBSERVATIONS: JONES.

No. of Chart.	Date. 1858.	Long. of Sun.	Lat. of Obs.	t	Elongation of Vertex.		Lat. of Boundaries, Stronger Light.						Lat. of Boundaries, Diffuse Light.					
							Elong. 30°		Elong. 60°		Elong. 90°		Elong. 60°		Elong. 90°		Elong. 120°	
					Str.	Diff.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.
1	Apr. 2	12°	10°.5	208°	40°	60°	12°	3°	°	°	°	°	16°	0°	°	°	°	°
				210	44		4	6										
				218	48		1	9										
2	Apr. 4	14	16.9	210	40		9	2										
				216	46		6	5					22	0				
3	Apr. 5	15	18.8	207	40		11	2										
				213	49		6	5										
				216	54		5	6										
				220	56		4	6										
				224	61		0	11	3	2				3				
5	Apr. 7	17	22.3	226	54		6	7										
6	Apr. 8	18	22.3	220	48		9	3										
				227	53		5	9										
7	Apr. 9	19	22.8	218	38		10	1										
				224	52		1	5										
8	Apr. 26	36	22.2	245		90							16	14				
9	Apr. 29	39	23.9	240		76	10	4					14	6				
10	June 7	76	26.2	291	50	76	6	4					18	4				
11	June 8	77	26 2	294		76							12	5				
14	June 23	92	26.2	309	48	94	19	0					20	9				
				317	54													
15	June 24	93	26.2	310	50	94	26						24	20	14	6		
				318	58		27											
				325	68		31		18									
				333	78		31		21									
16	June 25	94	26.2	312	54	98	25						26	26	18	6		
				319	62		26		14	2								
17	June 27	96	26.2	314	48	124	25						31		28		14	13
				326	63		30		16	2								
				343		135							46		40		24	22
18	June 29	98	26.2	312	48		23											
				315	54	139	27						49		40	32	26	26
				328	64		32		14	20								
				330	75		34		26									
				345	97		34		31		20	12						
				353	106		34		31		25							
19	June 30	99	26.2	317	86	142	20		20	8			36		34	30	30	20
				324	74		36		27	15								
20	July 1	100	26.2	318	58	89	20						21	11				
				325	60	102	24						24					
				332	70		24		16	10			24		16	12		
				347		102							28		19	18		
21	July 2	100	26.2	334		86							26					
22	July 4	102	29.1	318	45	71	24	10					24	24				
				320	57	92	28						30		18	10		
				335		100							34		23	18		
24	July 5	103	30.8	321	56	88	25						26					
				329	56	94	25						27		14	11		
				337		98							28		18	18		
26	July 6	104	32.2	323	51	94	19						24		12	10		
				338	67	104	15	2					30		24	21		

TABLE X. — *Continued.*

No. of Chart.	Date. 1858.	Long. of Sun.	Lat. of Obs.	t.	Elongation of Vertex.		Lat. of Boundaries, Stronger Light.						Lat. of Boundaries, Diffuse Light.					
							Elong. 30°		Elong. 60°		Elong. 90°		Elong. 60°		Elong. 90°		Elong. 120°	
					Str.	Diff.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.
		°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
28	July 7	105	33.8	324	56	86	19						27	17				
				331		92							29		13	4		
29	July 8	106	35.2	332	49	89	16						22					
				340		95							25		14	10		
31	July 9	107	35.2	337	64	90			15	0			24					
				341	64	98			13	0			28		18	14		
41	Aug. 4	132	21.8	343	57	80	18						18	22				
				358		91							22		8	6		
45	Aug. 26	153	23.0	12		79							38					
46	Aug. 29	156	23.0	0	56	76	16						24	16				
47	Aug. 31	158	23.0	2	51	74	16						20	15				
48	Sept. 1	158	23.0	1	53	67	13						19	12				
				7		74							22	13				
				11	68				4	3								
51	Sept. 3	160	23.0	6	60	70	22						20	13				
58	Sept. 27	184	23.0	21	49	56	18											
				28		60												
				36									12					
59	Sept. 28	185	23.0	22	49	55	18											
				30		61							8	2				
				37		65							16					
61	Sept. 30	187	22.4	24	46	54	18											
				31		58												
				39		60												
63	Oct. 1	188	22.4	25	45	50	19											
				32		52												
				40		57												
				51		72							20	10				
65	Oct. 8	190	22.4	28	39	50	16											
				34		54												
				42		59												
				50									26					
68	Oct. 18	205	22.2	37									24					
69	Oct. 19	206	22.2	43		96							25		12	16		
70	Oct. 20	207	22.2	36	36	96	20	5					28		11	15		
				44		104							34		28	21		
71	Oct. 21	208	22.2	37	35		20	4										
				41		95	25						22	22	8	11		
				45		105							31		16			
				52		105												
72	Oct. 22	209	22.4	38	36	93	18	4					24		5	9		
				42	40	95	20						29		8	10		
				46		102	28						34		19			
				68		105							42		23			
73	Oct. 27	214	22.4	51		96							32		16	15		
				66		99							37		20	17		
74	Oct. 28	215	22.4	45		87							25					
				52		92							32		9	5		
76	Oct. 29	216	22.4	43	32		8	2										
				45	42	87	14						23					
				53	71	94	25		11	10			31		10	14		
				79	81	103							38		19	22		

TABLE X. — *Continued.*

No. of Chart.	Date. 1853-54.	Long. of Sun.	Lat. of Obs.	t.	Elongation of Vertex.		Lat. of Boundaries, Stronger Light.						Lat. of Boundaries. Diffuse Light.					
							Elong. 30°		Elong. 60°		Elong. 90°		Elong. 60°		Elong. 90°		Elong. 120°	
					Str.	Diff.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.
		°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
78	Oct. 31	218	22.4	47	30													
				51		92							23	20	6	10		
				55	71	100			10	9			28		16	21		
				70	77	106			18	9			40		24	25		
				85	95	109					11	6			36	28		
				107	92						4	3						
83	Nov. 4	222	22.4	79	79	106			17	10					30	22		
				89	82	110			20	10					34	24		
				104	94	114			17	10	8	8			36	24		
				119		120										25		
84	Nov. 5	223	22.4	90	79	108			18						30	28		
				105	97	118					6	8			35	24		
				120	102						10	8						
86	Nov. 22	240	22.3	77	56	98							24	26	12	15		
88	Dec. 21	269	23.1	98	76				9	9								
				105	82	120			11	16			20	29	18	18		
89	Dec. 28	276	22.3	112	72	122			8	8			26	24	21			
				119	85	132			10	8			26	24	23	18		
				127	98	137			10	10	8	6		24	25	19		
				142	110	148			10		10	8		24	26	20		
91	Dec. 29	277	22.3	109		99							16	16	10	10		
				113	64				5	5								
				117	68	107			6	6			28	21	15	16		
				120	76	113			9	7			23	21	16	16		
				135	82	134			10	7			23	21	17	17	10	12
				150		147							30	22	26	19	20	16
93	Dec. 30	278	22.3	110	63	105	16	10	6	7			10	15	7	6		
				118	70		16	10	9	9								
				119		127							18	17	13	11	8	6
				125	79	134			11	9			24	21	20	17	13	14
				129	90				12	11								
				137	94	144			12	11	6	7	24	20	21	18	16	16
				152		147							24	20	22	19	18	18
96	Jan. 2	282	22.3	139	87	132			8	8					15	16	8	11
				154	91	144			8	8	1	1			21	16	14	14
				169		144									21	16	13	14
				192		142									18	16	11	13
	Jan. 3			207		142									18	16	11	13
98	Jan. 3	283	22.3	153	100	138					6	5			14	15	10	13
				163	112						6	5						
				178		145									19	20	13	17
				193		145											16	17
	Jan. 4			208		145											16	17
104	Jan. 18	298	23.7	125	66	119	9	7	4	4			17	16	11	14		
				140	76	126			6	6			21	19	15	17	8	9
105	Jan. 24	304	26.2	149		124							17	16	12	14	6	7
106	Jan. 25	305	26.2	140	67	122	10	7	5	5			12	12	8	8	2	4
				151	80	136			8	8			24	14	18	11	10	7
107	Jan. 26	306	26.2	156	79	132			9	7			24	16	19	14	10	6
				171	83	132			12	9			27	19	21	16	12	8
				178	90				12	9								

TABLE X. — *Continued.*

No. of Chart.	Date. 1854.	Long. of Sun.	Lat. of Obs.	t.	Elongation of Vertex.		Lat. of Boundaries, Stronger Light.						Lat. of Boundaries, Diffuse Light.					
							Elong. 30°		Elong. 60°		Elong. 90°		Elong. 60°		Elong. 90°		Elong. 120°	
					Str.	Diff.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.
109	Jan. 27	307°	26.2°	142°	78°	121°	°	°	9°	7°	°	°	25°	17°	18°	12°	3°	4°
				157	84	125			12	10			25	18	20	14	9	8
111	Jan. 30	310	26.2	157	71	118			10	9			28	19	19	15		
				158	63				2	2								
113	Jan. 31	311	26.5	161	60	114							24	14	14	10		
				166	71				7	6								
				176	79	118			12	8			26	18	17	13		
117	Feb. 15	326	35.3	160	70				4	7			16	17	13	10		
				162	81				6	9								
118	Feb. 17	328	35.3	162	65		13	7	6	6			22	15	14	12		
				170	80		14	8	9	7			24	18	17	16		
				177	85				11	7			24	18	17	16		
				192	91				12	8	4	3	24	18	17	16		
119	Feb. 18	329	35.3	163	71				7	8			19	13	12	10		
				178	91				10	7	2	4	23	17	16	14		
				193	95				11	7	4	6	23	17	16	14		
120	Feb. 20	331	35.3	165	56		10	8					22	15	16	10		
				167	67		12	8	6	6								
				169	75		14	8	9	6								
121	Feb. 21	332	35.3	174	77				8	6			22	17	14	14		
				181	90				9	6								
122	Feb. 23	334	35.3	175	51		8	4					21	14	14	8		
				177	78				7	7								
				180	84				9	9								
				190	93				9	9	3	3	24	16				
123	Feb. 24	335	35.4	180	84				7	6			21	19		16		
				199	90				9	9			26	22		20		
124	Feb. 25	336	35.4	174	85		13	8	8	7			23	14		11		
				200	95				10	7	4	4	27	18		15		
127	Mar. 18	357	35.4	201	72		10	8	5	6			22	12				
				221	79				10	9			22	12				
128	Mar. 20	359	35.4	200	73				7	4				10				
				223					9	7								
129	Mar. 25	4	35.4	209		108			7	4				13	12	8		
				235	104				9	7	6	4						
131	Mar. 27	6	35.4	207	60		9	6						12				
				237	101				9	6	7	4						
133	Mar. 28	7	35.4	246	105	116			10	6	8	4			18			
135	Mar. 29	8	35.4	212	62	110	10	6	4	0				12	16	9		
				232		118								16	20	12		
				247	104				12	6	10	3						
136	Mar. 30	9	35.4	214	62	114	10	6	6	*1*			24	16	20	9		
				233		114							24	16	20	9		
				238	101				13	6	10	0						
				248	104				15	7	12	2						
138	Apr. 17	27	35.3	230	86	111			11	4			22		18	6		
				247	96	118			11	6	9	1	22		20	12		
				274	96	118			11	6	9	1	22		20	12		
139	Apr. 18	28	34.7	237	84	116			11	4			22		20	9		
				252	97	121			15	8	11	*2*	24		22	14		

TABLE X.— *Continued.*

No. of Chart.	Date. 1854.	Long. of Sun.	Lat. of Obs.	t.	Elongation of Vertex.		Lat. of Boundaries, Stronger Light.						Lat. of Boundaries, Diffuse Light.					
							Elong. 30°		Elong. 60°		Elong. 90°		Elong. 60°		Elong. 90°		Elong. 120°	
					Str.	Diff.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.
		°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
140	Apr. 20	30	34.7	237	82		16	9	11	5								
				239		98							22		14	3		
				254	93	116			12	7	6	1	25		21	13		
				269	93	116			12	7	6	1	25		21	13		
141	Apr. 21	31	34.7	238	79				10	4								
				240		102							20		14	9		
				255	98	115			8	5	4	2	26		21	14		
				270	98	115			8	5	4	2	26		21	14		
143	Apr. 24	34	34.7	243	90	107			11	4			16		20	10		
				258	96	112			12	6	7	2	19		24	12		
				273	96	112			12	6	7	2	19		24	12		
144	Apr. 25	35	34.7	244	90	108	15	6	10	5			16		19	12		
				259	95	116			12	5	6	2	20		25	14		
146	Apr. 26	36	34.7	245	89	111			10	4			16	14	20	10		
				260	96	118			12	6	6	3	21	16	26	13		
148	Apr. 28	38	34.7	254	92	110			10	4	4	0	26		21	13		
				269	100	116			11	7	6	4	28		24	16		
149	Apr. 29	39	34.7	248	88	107			10	4			26		20	12		
152	May 15	54	40.2	273	71	106			16	8	7	8	28	13	22	8		
				281	76	116			18		9	3	31	15	26	12		
153	May 16	55	41.8	275	71	108	16		7	2			27	15	24	12		
				285	76	120	18		10	2			32	20	29	18		
				294	90	120	21		13	2			32	20	29	18		
154	May 17	56	41.8	280	74	104	15		8	2			30	15	24	12		
				288	91	114	19		12	2	3	0	32	16	28	14		
				295	99	120	21		14	2	7	2	32	16	30	16		
155	May 19	58	41.8	282	74	111	18		7	3			30	16	25	13		
				297	97	118	20		12	3	4	3	31		29	16		
156	May 20	59	41.8	287	98		67		11	4	6	4						
				288		114							30	20	27	16		
				298	102	119	70		14	2	8	3	34	20	30	18		
158	May 22	61	41.8	285	92	110	20		13	5	4	2	36	19	30	13		
				303	99	124	20		14	5	7	4	37	19	33	16	16	4
161	May 29	68	41.8	294	100	124	23		15	4	7	4	36	20	30	17	17	8
				314	106	142	27		19	4	11	4	38	20	35	18	31	16
166	June 21	90	34.7	313	87	120			12	3			30		28	16		
				315	97	122			15	3	7	3	32		27	16	10	4
				330	105	125			18	3	10	3	36		32	16	18	8
167	June 22	91	34.7	316	103	119			18	4	9	3	32	18	25	15		
				331	112	132			23	3	12	2	42		39	18	25	12
168	June 24	93	34.7	318	104	134			15	3	8	2	34		29	18	23	13
				333	114	138			18	3	11	2	40		34	18	27	16
169	June 27	96	33.0	321	98	127	26		16	4	5	3	36		29	18	15	10
				336	106	131	28		18	4	8	3	40		32	18	20	14
171	June 29	98	28.5	338	106	128			16	4	10	3	36		33	15	22	10
179	July 13	111	25.2	337	116	130			16	4	12	0	35		30	17	23	9
180	July 14	112	25.2	327	85	120			13	1			31		26	15		
				338	102	130			14	1	8	0	35		28	18	20	9
				349	114	133			17	1	11	0	38		31	18	23	12
181	July 15	113	25.2	324	76	119	16	2	10	0			29		22	14		
				339	98	126			14	1	9	1	34		28	14	18	6
				354	118	128			17	3	12	1	38		31	15	22	9

TABLE X. — *Continued.*

No. of Chart.	Date. 1854.	Long. of Sun.	Lat. of Obs.	t.	Elongation of Vertex.		Lat. of Boundaries, Stronger Light.						Lat. of Boundaries, Diffuse Light.					
							Elong. 30°		Elong. 60°		Elong. 90°		Elong. 60°		Elong. 90°		Elong 120°	
					Str.	Diff.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.
182	July 18	115°	25.2°	341°	100°	123°	°	°	12°	3°	8°	0°	31°	°	24°	14°	10°	2°
				351	118	127			16	3	12	0	35		28	14	18	6
183	July 19	116	25.2	335	94	120			12	2	6	0	33		28	14		
				350	111	121			18	3	12	2	37		30	14	14	0
184	July 20	117	25.2	332	99	122			12	2	8	0	32		25	14	12	2
				343	107	124			13	4	9	2	35		28	14	16	4
				350	112	124			15	4	12	2	38		31	14	20	4
185	July 21	118	25.2	336	91	120			12	3	3	0	31		24	14		
186	July 22	119	25.2	334	91	118			12	2	3	0	33		24	13		
				349	97	122			16	2	11	2	40		29	13	14	2
				356	110	122					12	2	40		29	13	14	2
188	July 24	121	25.6	332	68		17	3	9	2								
				336	92	119			13	3	6	2	33		26	16		
				348	104	123			15	3	11	2	38		31	16	14	4
				358		123							38		31	16	14	4
190	July 25	122	25.0	337	88	114			11	3			38	15	26	14		
				348	106	118			15	3	10	2	38	15	30	14		
196	Aug. 12	140	14.6	343	90	106			15	2			32		21	13		
				358	92	108			17	2	8	2	35		24	13		
197	Aug. 17	144	14.3	348	87		17		11	2			34	20	25	14		
				8	92				14	4	6	1	34	20	25	14		
				18	96				14	4	7	2	34	20	27	14		
198	Aug. 18	145	14.4	349	86	101	17		11	3			32		21	10		
				357	92				14	5	6	1						
				12	95				14		7	2						
200	Aug. 21	148	14.7	352	84	99			12	3			29	20	20	12		
				8	88				12	3			31	20	24			
202	Aug. 22	149	15.8	353	89	100	16		11	4			33	20	23	13		
				8	93				14	4	7	0	38		28			
204	Aug. 23	150	18.0	355	86				11	3								
				0	88				12	3			34	20	25	14		
206	Aug. 25	152	20.8	0	84				10	4								
				4	86				12	4								
				11	90	100							31	19	19			
212	Sept. 12	169	22 2	11	74		20	4	8	2			34					
				18	77		24	4	11	2			38					
213	Sept. 13	170	23.1	12	69		24	6	7	1			32	10				
				20	74				9	1								
214	Sept. 14	171	24.1	13	73		25		8	1			31	11				
				21	77		30		10	1			31	11				
215	Sept. 16	173	27 5	15	72		26		7	1			30					
				20	75		30		10	3			30					
218	Sept. 20	177	33.5	18			21		7	1								
				19									37					
				25		111	21		7	2			41		22	19		
				36		114							42		26	19		
220	Sept. 23	180	34.7	25		110	12		6	3			32		16	17		
				40		111							36		21	17		
224	Oct. 11	198	35.4	34			23											
				38					6	4								
				40		104							34		21	16		
				44					8									

TABLE X. — *Continued.*

No. of Chart.	Date. 1854.	Long. of Sun.	Lat. of Obs.	t.	Elongation of Vertex.		Lat. of Boundaries, Stronger Light.						Lat. of Boundaries, Diffuse Light.					
							Elong. 30°		Elong. 60°		Elong. 90°		Elong. 60°		Elong. 90°		Elong. 120°	
					Str.	Diff.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.
225	Oct. 12	199°	35°.5	41°	°	100°	°	°	°	°	°	°	31°	°	17°	13°	°	°
				43			15											
				46		103							34		22	15		
226	Oct. 14	201	33.8	45		101	25		6				30		16	16		
				53		104							36		22	17		
227	Oct. 16	208	33.8	38			28											
				40		90	25						28					
				50		98	27						32		14	16		
229	Oct. 16	203	33.0	40		91	24		4				28		6	2		
				48		99	28		8				34		18	14		
230	Oct. 17	204	31.9	40			28											
				43		98			6				28		14	14		
231	Oct. 18	205	30.7	40			23		2									
				41		92							30		9	7		
234	Oct. 21	208	24.8	43		93	20	4	8				28		9	8		
235	Oct. 23	210	21.3	47	75	93	22		3	4			30		15	2		
				62	80	98							34		19	7		
239	Nov. 11	229	23.9	66		96							31	27	20	14		
				70	64				4	5								
				75	69				4	5								
240	Nov. 13	231	26.5	68	66	82	12		4	5			32	15				
242	Nov. 20	238	36.9	68	67	84			5	4			28	19				
				83	76	93			6	5			30	18	10	8		
244	Nov. 22	240	37.8	75	68	84			6	4			27	15				
249	Dec. 7	255	38.0	83	78	106	7		6	5			26	22	17	13		
				95	80		7		8	5								
250	Dec. 8	256	38 0	85	77	104			5	5			24	22	16	16		
				100	81	104			7	5			24	22	16	16		
251	Dec. 9	257	38.0	86	78	102	6		5	6			24	21	18	15		
				101	82	104			8	6			28	21	20	15		
				108	86	104			8	6			28	21	20	15		
252	Dec. 11	259	38.0	84	76	98			6	4			21	20	15	9		
				95	81	100			7	5			24	20	20	10		
253	Dec. 12	260	38.0	85	73	94			6	3			22	19	14	4		
				100	78	98			7	4			24	20	19	8		
				113	83	98			6	3			24	20	19	8		
254	Dec. 13	261	37.8	86	74	96			7	3			20	20	13	8		
				101	80	100			6	4			25	20	19	10		
				116	84				4	3								
255	Dec. 15	263	37.8	134	112	122					7	4			16	19	3	4
256	Dec. 16	264	37.3	91	76	96			7	3			18		12	8		
				107	81	98			6	4			26		18	8		
				130							6							
258	Dec. 18	266	31.7	118	84	96			7	6			24	18	16	9		
				124	91	104			8	6	1	5	28	20	28	14		
260	Dec. 19	267	29.6	95	77	100			5	3			23	17	18	11		
				110	79	106			6	3			27	20	28	14		
				120	87				9	3								
262	Dec. 20	268	26.9	96	76	100	7		5	3			22	18	17	9		
				111	82	105			7	3			26	22	21	18		
				179		152											9	9

TABLE X. — *Continued.*

No. of Chart.	Date. 1854–55.	Long. of Sun.	Lat. of Obs.	t.	Elongation of Vertex		Lat. of Boundaries, Stronger Light.						Lat. of Boundaries, Diffuse Light.					
							Elong. 30°		Elong. 60°		Elong. 90°		Elong. 60°		Elong. 90°		Elong. 120°	
					Str.	Diff.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.
265	Dec. 22	270°	21.8°	129°	100°	112°	°	°	9°	5°	6°	2°	24°	21°	22°	18°	°	°
267	Dec. 25	273	16.5	184		162											8	10
273	Jan. 5	285	8.8	120	91		9	8	7	5	4	0	22	20	16	16	12	12
				133	130				7	12	5	9						
274	Jan. 6	286	8.8	121	94		10	10	7	6	4	2	21	20	14	16	8	12
				186	110				7	10	4	6	21	20	14	16		
275	Jan. 8	288	8.8	127	98		9	9	5	6	2	2	21	22	16	16		10
				133	102				7	8	4	4						
				140	112				7	11	4	6						
				145	122				8	13	5	8						
276	Jan. 9	289	8.8	128	88		9	10	6	6			19	22	11	19		
				189	96				7	8	4	4						
				141	102				7	11	4	6	19	22	11	19		
277	Jan. 10	290	8.8	131	94		10	12	7	8	4	4	19	22	11	17		
				133	91		8	9	6	6	2	2						
				136	94				7	8	4	4						
				140	101				7	10	4	5	19	22	11	17		
				155	115				7	13	4	8						
278	Jan. 11	291	8.8	130									19	26	11	20	4	14
				134	86		9	9	5	5								
				136	96				6	8	2	4						
				141	104				8	10	3	6						
				156	118				9	12	5	8	19	26	11	20	4	14
279	Jan. 12	292	7.1	132									19	25	12	19	5	14
				137	91		8	10	5	7	1	2						
				140	99		9	12	6	8	3	4						
				142	109				7	10	4	6						
				146	109				7	10	4	6	21	25	14	19	7	14
280	Jan. 15	295	0.3	134	100		8	18	5	11	2	6						
				137									17	23	10	18	4	12
				145	107				7	14	3	7						
				160	120				8	16	4	9						
281	Jan. 17	297	*2.9*	140	98				6	12	3	6	21	23	16	18	12	12
				150	119				7	15	4	8						
283	Jan. 18	298	*5.1*	140	92		9	14	6	8	3	3						
				143	77		7	10	4	5			13	23	10	18	6	12
				146	100		9	14	6	10	4	5						
				150	111				6	12	4	7	13	23	10	18	6	12
				163	123					14	5	10						
285	Jan. 20	300	*9.9*	161	120				6	10	4	7	18	22	13	16	8	12
				169	127				6	15	4	10						
289	Feb. 6	317	*33.0*	174	110				6	11	3	6		26	13	20		14
				186	115				6	14	3	8						
290	Feb. 7	318	*33.0*	173	110				8	12	4	7		24	14	18		12
				187	117				8	14	4	9		28	14	22		16
291	Feb. 8	319	*33.0*	173	110			20	6	14	3	8		30	15	22		14
				188	117				6	16	3	9		35	15	27		20
202	Feb. 9	320	*33.0*	174	108			19	6	13	3	7		28	14	22		16
				189	112			26	6	16	3	9		36	14	28		20
293	Feb. 12	323	*35.7*	184	108				4	13	2	8		28		22		14
294	Feb. 19	330	*52.0*	190	102						4	10				25		24

TABLE X. — *Continued.*

No. of Chart.	Date. 1855.	Long. of Sun.	Lat. of Obs.	t.	Elongation of Vertex.		Lat. of Boundaries, Stronger Light. Elong. 30°		Elong. 60°		Elong. 90°		Lat. of Boundaries, Diffuse Light. Elong. 60°		Elong. 90°		Elong. 120°	
					Str.	Diff.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.
		°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
295	Feb. 21	332	53.6	196	101						3	11				25		
				204	108						3	12				29		
300	Mar. 13	353	22.9	193	79			11	4	7			13	23		17		
				201	81			15	3	9								
				208					8	11				36		23		
301	Mar. 15	355	22.9	195	78			10	2	7				22		16		
				208					3	11			12	26		20		
303	Mar. 16	356	22.9	196	74			14	2	8			12	22		16		
				204	78				2	10			12	36		19		
				212						13				36		19		
305	Mar. 17	357	22.9	197	74			14	2	8			14	24		16		
				201	77				2	9								
				205	77				2	10				26		20		
				212						12								
308	Mar. 21	0	22.9	216					8	9				22				
				224										22				
314	Apr. 4	14	1.6	211				18		9				25				
315	Apr. 9	19	11.2	220	92		8	11	7	6	6	0		18				
				228	107	126			7	8	7	3	21	23	19	16	14	6
				239	114				7	10	7	5	21	28	19	16		8
				256	131				9	14	8	7	21	23	19	17	18	10
316	Apr. 10	20	13.1	219	88		9	13	8	5								
				234	109	134			10	10	9	3	18	28	17	16	16	8
				254	129				10	14	9	8	18	23	17	16	16	8
				268									18	23	17	16	16	8
317	Apr. 11	21	15.2	221	92		9	12	8	6	6	2		23		14		5
				241	112				9	10	8	4	29	26	28	16	27	8
319	Apr. 13	23	20.1	224	99		9	14	7	8	5	2						
				239	126				10	12	8	8	28	25	26	16	24	7
				254					11	14	9	9	28	26	26	18	24	9
321	Apr. 14	24	22.5	233	116				9	9	7	4	26	26	22	17	20	8
				248	130				13	10	10	6	26	28	22	19	20	10
				255	132				13	10	13	6						
323	Apr. 16	26	27.1	231	108		14	12	10	8	6	5	34	26	30	18	26	10
				246	122		20	14	15	10	9	8	34	26	30	18	26	10
				261					17	12	12	9						
326	Apr. 18	28	32.2	252	124				15	7	10	5	36	18	31	16	26	12
				267	142				17	11	12	9						

TABLE XI. — EVENING OBSERVATIONS: HEIS, WEBER, EYLERT, NEUMAYER.

No.	Observer.	Date.		Long. of Sun.	Lat. of Obs.	t.	Elong. of Vert.	Lat. of Boundaries. Elong. 30° N.	Elong. 30° S.	Elong. 60° N.	Elong. 60° S.	Elong. 90° N.	Elong. 90° S.
				°	°	°	°	°	°	°	°	°	°
1	Heis	1847	Mar. 14	354	50.8	202	55	11	9				
2	"	1847	Mar. 15	355	"	208	58	11	9				
3	"	1847	Mar. 16	355	"	204	62	21	10	5	2		
4	"	1847	Mar. 17	356	"	205	62	21	10	5	2		
5	"	1847	Mar. 18	357	"	206	62	23	12	6	1		
6	"	1848	Mar. 24	3	"	212	54	8	14				
7	"	1849	Jan. 22	302	"	152	82			7	14		
8	"	1849	Feb. 18	324	"	174	84			10	12		
9	"	1849	Mar. 19	358	"	207	67	17	13	1	8		
10	"	1849	Mar. 20	359	"	208	64	10	12	7	6		
11	"	1850	Mar. 5	345	"	186	62	12	15	7	5		
12	"	1850	Mar. 9	349	"	193	61	21	5	5	0		
13	"	1850	Mar. 13	353	"	208	62	23	5	7	*1*		
14	"	1850	Mar. 15	355	"	203	62	24	5	6	*1*		
15	"	1851	Jan. 23	303	"	138	72			11	8		
16	"	1851	Feb. 18	329	"	163	78	17	17	8	8		
17	"	1851	Feb. 23	334	"	188	77	11	15	5	5		
18	"	1851	April 1	11	"	220	57	12	10				
19	"	1851	Dec. 18	266	"	102	78	11		7	5		
20	"	1851	Dec. 28	271	"	107	80	35	12	28	7		
21	"	1852	Jan. 10	290	"	117	70	20	11	13	2		
22	"	1852	Jan. 19	299	"	134	90			18	11		
23	"	1852	Jan. 20	300	"	135	90	30		18	7		
24	"	1852	Mar. 19	358	"	214	58	17	13				
25	"	1852	Mar. 20	359	"	216	56	24	11				
26	"	1852	Dec. 11	259	52.0	110	81			19	7		
27	"	1853	Jan. 3	283	"	118	78			16	8		
28	"	1853	Jan. 4	284	"	112	74			14	3		
29	"	1853	Jan. 27	307	"	185	80	26	15	13	8		
30	"	1853	Jan. 29	309	"	144	85			12	11		
31	"	1853	Feb. 28	339	"	192	69			8	4		
32	"	1853	Mar. 1	341	"	189	68	12	12	7	2		
33	"	1853	Mar. 11	351	"	206	66	24	11	8	0		
34	"	1853	Mar. 27	6	"	223	50	22	4				
35	"	1853	Mar. 28	7	"	216	54	19	9				
36	"	1853	Mar 30	9	"	218	56	19	8				
37	"	1853	April 28	38	"	266	60	14	9				
38	"	1853	May 4	43	"	274	62	24		10	*2*		
39	"	1853	Aug. 9	137	"	33	96			18	4		
40	"	1853	Dec. 1	249	"	78	86			19	5		
41	"	1853	Dec. 2	250	"	78	94			12	8	7	1
42	"	1853	Dec. 25	273	"	94	83			12	15		
43	"	1854	Jan. 18	298	"	133	86	27	15	14	8		
44	"	1854	Jan. 19	299	"	126	76	22		10	8		
45	"	1854	Jan. 24	304	"	154	84			10	11		
46	"	1854	Feb. 28	339	"	199	77			12	8		
47	"	1854	Mar. 16	355	"	204	65	30	7	7	8		
48	"	1854	Mar. 18	357	"	206	64	26	11	6	2		
49	"	1854	April 16	26	"	250	61	18	6				
50	"	1854	April 17	27	"	266	62	21	9				
51	"	1854	April 18	28	"	267	73	26	18	14	6		
52	"	1855	Jan. 10	290	"	125	70	18	12	10	5		

TABLE XI. — *Continued.*

No.	Observer.	Date.		Long. of Sun.	Lat. of Obs.	t.	Elong. of Vert.	Lat. of Boundaries.					
								Elong. 30°		Elong. 60°		Elong. 90°	
								N.	S.	N.	S.	N.	S.
				°	°	°	°	°	°	°	°	°	°
53	Heis	1855	Jan. 18	298	52.0	148	96			19	16		
54	"	1855	Feb. 9	320	"	170	86			18	11		
55	"	1855	Feb. 16	327	"	176	87	28	11	13	7		
56	"	1855	Mar. 5	345	"	193	78			11	4		
57	"	1855	Mar. 16	355	"	204	72	25	15	11	4		
58	"	1855	July 22	119	"	30	94	43		32		12	
59	"	1856	Feb. 8	314	"	149	89			18	11		
60	"	1856	Mar. 7	347	"	195	69	28	10	8	5		
61	"	1856	Mar. 25	4	"	220	67	15	19	5	7		
62	"	1856	April 23	33	"	265	65	20	18				
63	"	1857	Feb. 14	325	"	174	82			20	7		
64	"	1857	Feb. 15	326	"	175	80	30	17	17	8		
65	"	1857	Feb. 23	334	"	168	74			13	8		
66	"	1857	Feb. 24	335	"	169	78			16	8		
67	"	1857	Mar. 16	355	"	196	74	35	17	15	13		
68	"	1857	Mar. 17	356	"	205	74			11	11		
69	"	1857	April 15	25	"	249	59	20	15				
70	"	1857	Dec. 8	256	"	107	101			14	17	10	6
71	"	1857	Dec. 18	266	"	117	82	38	8	30	5		
72	"	1858	Jan. 8	283	"	118	89	20		13	12		
73	"	1858	Feb. 7	318	"	153	76	21	13	9	8		
74	"	1858	Mar. 5	345	"	193	70	24		10	8		
75	"	1858	April 4	14	"	228	58	18	13				
76	"	1858	April 14	24	"	240	80	17	9	8	4		
77	"	1859	Jan. 5	285	"	120	85			15	15		
78	"	1859	Jan. 22	302	"	144	111			16	12		
79	"	1859	Jan. 27	307	"	142	106			16	14	9	4
80	"	1859	Mar. 7	347	"	210	74			16	8		
81	"	1859	Mar. 22	1	"	210	65	24		10	0		
82	"	1859	Mar. 28	7	"	216	61	26	17				
83	"	1859	Nov. 20	238	"	90	85			8	2		
84	"	1859	Dec. 20	268	"	104	70	21	8	8	3		
85	"	1860	Jan. 12	292	"	127	88	25		14	7		
86	"	1860	Feb. 9	320	"	162	88	16	9	9	6		
87	"	1860	Feb. 11	322	"	157	92			12	11	4	0
88	"	1860	Feb. 15	326	"	171	89	29		17	8		
89	"	1860	Feb. 23	334	"	175	88			17	7		
90	"	1860	April 7	17	"	234	66	25		6	2		
91	"	1861	Jan. 1	281	"	116	67	16		8	1		
92	"	1861	Jan. 8	288	"	116	78	25	11	13	1		
93	"	1861	Jan. 9	289	"	124	78			16	4		
94	"	1861	Feb. 2	313	"	163	71	22	18	8	7		
95	"	1861	Feb. 10	321	"	171	85			13	9		
96	"	1861	Mar. 9	349	"	197	72	24	11	10	2		
97	"	1861	Mar. 12	352	"	189	80	22	15	12	6		
98	"	1861	April 6	16	"	240	73	25	18	9	12		
99	"	1861	April 9	19	"	243	70	25	9	8	4		
100	"	1862	Feb. 18	329	"	178	79			18	7		
101	"	1862	Feb. 22	333	"	182	80	24	17	13	8		
102	"	1862	Mar. 17	356	"	205	63	23	11				
103	"	1862	Mar. 27	6	"	215	57	23	18				
104	"	1862	Mar. 31	10	"	226	57	26	14				

TABLE XI. — *Continued.*

No.	Observer.	Date.		Long. of Sun.	Lat. of Obs.	*t*.	Elong. of Vert.	Lat. of Boundaries.					
								Elong. 30°		Elong. 60°		Elong. 90°	
								N.	S.	N.	S.	N.	S.
				°	°	°	°	°	°	°	°	°	°
105	Heis	1862	April 25	35	52.0	259	77			9	4		
106	"	1862	April 29	39	"	263	80	22	8	11	5		
107	"	1862	Dec. 16	264	"	85	95			15	8		
108	"	1862	Dec. 22	270	"	95	78	26	6	18	5		
109	"	1863	Jan. 9	289	"	120	94			21	6	4	2
110	"	1863	Jan. 15	295	"	122	86			13	5		
111	"	1863	Feb. 5	316	"	161	70			13	6		
112	"	1863	Feb. 9	320	"	170	86			12	12		
113	"	1863	Feb. 14	325	"	174	86			12	10		
114	"	1863	Feb. 17	328	"	177	87			16	10		
115	"	1863	Mar. 8	348	"	196	80	28	14	12	6		
116	"	1863	April 6	16	"	244	77			11	7		
117	"	1863	April 10	20	"	244	76			11	7		
118	"	1863	April 18	23	"	248	74	26	19	15	6		
119	"	1863	April 19	29	"	253	70	25		13	10		
120	"	1864	Jan. 4	284	"	126	88			15	8		
121	"	1864	Jan. 10	290	"	125	95			18	12	2	6
122	"	1864	Jan. 26	306	"	184	84			12	11		
123	"	1864	Jan. 30	310	"	187	97			15	11		
124	"	1864	Feb. 28	339	"	192	87			17	9		
125	"	1864	Mar. 10	350	"	205	84			11	13		
126	"	1864	Mar. 29	8	"	217	64	21	12	5	0		
127	"	1864	April 2	12	"	228	64	20	13	2	1		
128	"	1864	April 5	15	"	232	74			10	6		
129	"	1864	April 6	16	"	232	74			10	5		
130	"	1864	April 8	18	"	242	73	24	10	9	6		
131	"	1864	April 24	34	"	265	80			13	13		
132	"	1864	April 30	39	"	270	76	21		11	4		
133	"	1864	May 3	42	"	277	78			14	7		
134	"	1864	May 8	47	"	294	75	18		9	10		
135	"	1864	Dec. 26	274	"	102	80	34	12	21	2		
136	"	1865	Jan. 28	308	"	136	95			18	7	1	3
137	"	1865	Feb. 14	325	"	174	84			19	6		
138	"	1865	Feb. 22	333	"	167	86			18	10		
139	"	1865	Mar. 19	358	"	207	77	21	15	8	8		
140	"	1865	April 20	30	"	250	71			9	5		
141	"	1865	April 22	32	"	256	78	20	15	13	8		
142	"	1865	April 24	34	"	258	73			15	2		
143	"	1865	Dec. 15	263	"	114	94			17	9		
144	"	1866	Jan. 5	285	"	135	94	19	10	13	7	2	1
145	"	1866	Feb. 8	319	"	169	89			14	14		
146	"	1866	Feb. 11	322	"	180	91			14	10		
147	"	1866	Mar. 3	343	"	187	68	26	12	8	8		
148	"	1866	Dec. 30	279	"	114	71	26	3	16	2		
149	"	1867	Jan. 5	285	"	112	81			14	14		
150	"	1867	Feb. 1	312	"	147	90			11	11		
151	"	1867	Feb. 2	318	"	148	97			27	11	8	0
152	"	1867	Feb. 23	334	"	172	81	26		14	5		
153	"	1867	Feb. 26	337	"	186	89			16	6		
154	"	1867	Mar. 2	342	"	190	87			17	7		
155	"	1867	April 1	11	"	224	75			8	5		
156	"	1867	Dec. 24	272	"	100	88			13	7		

TABLE XI. — *Continued.*

No.	Observer.	Date.		Long. of Sun.	Lat. of Obs.	*t*.	Elong. of Vert.	Lat. of Boundaries.					
								Elong. 30°		Elong. 60°		Elong. 90°	
								N.	S.	N.	S.	N.	S.
157	Heis	1868	Jan. 20	300°	52.0°	150°	97°	°	°	23°	15°	13°	*3*°
158	"	1868	Feb. 11	322	"	172	93			29	5	10	*2*
159	"	1868	Feb. 17	328	"	177	92			20	9		
160	"	1868	Mar. 25	4	"	228	78			12	8		
161	"	1869	Jan. 8	288	"	123	94	24	10	16	6	3	2
162	"	1869	Feb. 5	316	"	159	93			13	11		
163	"	1869	Mar. 5	345	"	198	82			15	9		
164	"	1870	Jan. 25	305	"	140	101			16	15	7	4
165	"	1870	Jan. 30	310	"	145	99			16	9	4	4
166	"	1870	Feb. 22	333	"	182	80			18	2		
167	"	1870	Feb. 27	338	"	187	78			15	8		
168	"	1870	Mar. 3	343	"	191	77			14	9		
169	"	1870	Mar. 6	346	"	239	75			18	7		
170	"	1870	April 1	11	"	227	65	23	16	5	8		
171	"	1870	April 2	12	"	228	71			9	2		
172	"	1870	Dec. 11	259	"	95	80			10	12		
173	"	1871	Jan. 15	295	"	130	104			19	18		
174	"	1872	Mar. 4	344	"	192	76			12	8		
175	"	1872	Mar. 11	351	"	206	72	25	17	10	4		
176	"	1874	Feb. 5	316	"	151	93			16	11		
177	"	1874	Feb. 11	322	"	157	89			14	9		
178	"	1874	Feb. 13	324	"	173	90			14	4		
179	"	1875	Jan. 7	287	"	187	117					9	11
180	"	1875	Jan. 27	307	"	120	108			14	17	5	5
181	"	1875	Feb. 5	316	"	155	96			15	15	4	3
182	"	1875	Feb. 23	334	"	188	94			13	11		
183	"	1875	Mar. 3	343	"	191	89			12	8		
184	"	1875	Mar. 4	344	"	192	95	27	15	12	11	2	2
185	"	1875	Mar. 5	345	"	198	95	25	13	16	10	7	0
186	Weber	1865	April 20	30	"	254	79	15		8	9		
187	"	1865	April 21	31	"	255	81			11	10		
188	"	1865	April 23	33	"	257	79			14	6		
189	"	1865	April 27	37	"	261	80			14	4		
190	"	1866	Jan. 5	285	"	135	74	22	8	11	3		
191	"	1866	Mar. 4	344	"	207	82	17	14	8	5		
192	"	1866	Mar. 5	345	"	198	82	18	15	7	5		
193	"	1866	Dec. 30	278	"	106	64			2	5		
194	"	1867	Feb. 2	313	"	168	76			10	9		
195	"	1867	Feb. 3	314	"	164	76	24	24	11	8		
196	"	1867	Feb. 23	334	"	183	84	22	20	9	6		
197	"	1867	Feb. 26	337	"	186	83	22	15	10	5		
198	"	1867	Mar. 2	342	"	190	79	20	14	7	4		
199	"	1867	Mar. 25	4	"	218	72	19	17	10	6		
200	"	1867	Mar. 26	5	"	214	73	22	14	9	5		
201	"	1867	Mar. 29	8	"	217	70	22	7	5	2		
202	"	1867	Mar. 30	9	"	218	69	20	10	5	2		
203	"	1867	April 25	35	"	252	65	21	13				
204	"	1867	May 5	44	"	268	65	18	14	7	*1*		
205	"	1869	Jan. 11	291	"	141	78	23	9	14	2		
206	"	1869	Jan. 12	292	"	142	79			13	1		
207	"	1869	Jan. 13	293	"	143	77			12	2		
208	"	1869	Feb. 5	316	"	166	84	25	17	13	9		

TABLE XI. — *Continued.*

No.	Observer.	Date.		Long. of Sun.	Lat. of Obs.	t.	Elong. of Vert.	Lat. of Boundaries. Elong. 30° N.	Elong. 30° S.	Elong. 60° N.	Elong. 60° S.	Elong. 90° N.	Elong. 90° S.
				°	°	°	°	°	°	°	°	°	°
209	Weber	1869	Feb. 6	317	52.0	167	84	24	18	14	8		
210	"	1869	Feb. 14	325	"	174	82	26	7	14	2		
211	"	1869	Mar. 3	343	"	191	87			12	8		
212	"	1869	Mar. 8	348	"	196	82			12	6		
213	"	1869	Mar. 30	9	"	226	77	19	11	9	4		
214	"	1869	Mar. 31	10	"	226	76	20	12	8	4		
215	"	1869	April 1	11	"	228	76	19	12	8	5		
216	"	1869	April 5	15	"	231	75	20	11	8	4		
217	"	1869	April 11	21	"	238	70	19	8	9	0		
218	"	1870	Jan. 25	305	"	155	88			12	6		
219	"	1870	Jan. 28	308	"	158	86	24	10	11	5		
220	"	1870	Jan. 31	311	"	146	86			12	7		
221	"	1870	Feb. 22	333	"	182	87			12	6		
222	"	1870	Feb. 27	338	"	187	89			14	6		
223	"	1870	Feb. 28	339	"	188	87			11	4		
224	"	1870	Mar. 2	342	"	190	87			13	2		
225	"	1870	Mar. 3	343	"	183	87			13	4		
226	"	1870	Mar. 5	345	"	193	87	25	14	12	2		
227	"	1870	Mar. 19	358	"	207	86	19	11	9	2		
228	"	1870	April 1	11	"	220	84			10	6		
229	"	1870	April 3	13	"	222	80			10	8		
230	"	1870	April 20	30	"	239	78			10	8		
231	"	1870	April 22	32	"	241	80			9	7		
232	"	1870	Dec. 21	269	"	105	100			19	10	4	5
233	"	1871	Jan. 13	293	"	128	91			16	12		
234	"	1871	Jan. 15	295	"	122	91			19	11		
235	"	1871	Mar. 12	352	"	200	85			9	11		
236	"	1871	Mar. 19	358	"	207	82			5	7		
237	"	1871	Mar. 22	1	"	210	79	18	20	8	8		
238	"	1871	April 8	18	"	235	88			10	6		
239	"	1871	April 14	24	"	240	87			9	9		
240	"	1873	Jan. 25	305	"	132	88			17	13		
241	"	1873	Jan. 26	306	"	133	89			16	13		
242	"	1873	Feb. 21	332	"	166	88			11	7		
243	"	1873	Feb. 27	338	"	191	90			11	12		
244	"	1873	Mar. 21	0	"	209	99			13	13	4	5
245	"	1873	Mar. 24	3	"	212	99	24	20	13	12	2	8
246	"	1873	Mar. 27	6	"	215	99	25	19	14	14	3	6
247	"	1873	April 20	30	"	239	92			18	7	5	0
248	"	1874	Jan. 7	287	"	187	90			12	10		
249	"	1874	Feb. 5	316	"	147	98			11	4		
250	"	1874	Feb. 8	319	"	154	95	21	16	10	9	8	1
251	"	1874	Feb. 9	320	"	159	96			12	7	4	1
252	"	1874	Mar. 5	345	"	189	91	21	14	9	9		
253	"	1874	Mar. 6	346	"	190	93			9	8	2	0
254	"	1874	Mar. 9	349	"	197	89			11	8		
255	"	1874	April 4	14	"	288	96			14	10	5	1
256	"	1874	April 12	22	"	238	109			17	10	10	4
257	"	1874	April 17	27	"	251	110			17	10	12	4
258	"	1874	Dec. 2	250	"	71	115					13	6
259	"	1874	Dec. 4	252	"	73	116			18	16	10	7
260	"	1874	Dec. 7	255	"	76	114			19	19	11	8

TABLE XI. — *Continued.*

No.	Observer.	Date.		Long. of Sun.	Lat. of Obs.	t.	Elong. of Vert.	Lat. of Boundaries.					
								Elong. 30°		Elong. 60°		Elong. 90°	
								N.	S.	N.	S.	N.	S.
261	Weber	1875	Jan. 24	304°	52°.0	139°	95°	°	°	13°	13°	°	°
262	"	1875	Jan. 28	308	"	139	97			15	11		
263	"	1875	Feb. 5	316	"	144	104			13	8		
264	"	1875	Feb. 7	318	"	153	108			14	7		
265	"	1875	Feb. 22	333	"	171	96	24	11	12	6		
266	"	1875	Feb. 25	336	"	174	95	25	11	12	4		
267	"	1875	Mar. 26	5	"	214	100	25	20	14	10	7	1
268	"	1875	Mar. 28	7	"	216	98	26	19	15	10		
269	"	1875	April 5	15	"	232	98	26	19	16	10		
270	"	1875	April 23	33	"	250	117			21	18	12	6
271	"	1875	April 26	36	"	260	115			20	11		
272	"	1875	May 1	40	"	264	116			24	9		
273	Eylert	1873	May 27	66	25.8	282	80	13	8	13	0		
274	"	1873	May 28	67	22.9	291	80	25	5	12	2		
275	"	1873	June 12	81	*2.8*	276	73	23	9	8	3		
276	"	1873	June 13	82	*4.4*	282	64	26	18	4	1		
277	"	1873	June 15	84	*9.1*	284	69	35	12	9	8		
278	"	1873	June 16	85	*10.8*	265	64	17	12	3	2		
279	"	1873	June 22	91	*15.8*	286	60	27	15				
280	"	1873	July 15	112	*35.3*	313	66	6	21	2	8		
281	"	1873	July 17	114	*35.9*	320	80	9	26	6	6		
282	"	1873	Aug. 11	139	*34.6*	335	62	10	9	*3*	4		
283	"	1873	Aug. 23	150	*34.6*	353	78			7	11		
284	"	1873	Sept. 13	170	*35.2*	16	72	14	15	6	10		
285	"	1873	Nov. 13	231	*5.8*	79	86			10	18		
286	"	1873	Nov. 14	232	*3.9*	74	74	10	20	11	1		
287	"	1873	Nov. 21	239	5.6	76	70	15	15	11	*1*		
288	"	1873	Dec. 8	256	20.0	96				7	6	7	*1*
289	"	1873	Dec. 9	257	20.7	112				8	4	8	*1*
290	"	1873	Dec. 18	266	33.4	106				12	8	1	8
291	"	1873	Dec. 20	268	34.9	99		3		8	8	8	2
292	"	1873	Dec. 21	269	35.4	105	110			14	11	8	3
293	Neumayer	1859	Sept. 24	181	*37.8*	26		14	14	2	10		
294	"	1860	Aug. 8	136	*37.8*	332	68	12	18	1	2		
295	"	1864	July 31	128	*29.3*	354	94			8	10		
296	"	1864	Aug. 2	130	*23.3*	341				4	6		

TABLE XII. — EVENING OBSERVATIONS: SCHMIDT.

No.	Date.		Lat. of Obs.	Incl. of Ecl.	Az. of Pole.	Long. of Sun.	Elong. of Zen.	Latitude of Boundaries.									
								Elong. 30°		Elong. 60°		Elong. 90°		Elong. 120°		Elong. 150°	
								N.	S.	N.	S.	N.	S.	N.	S.	N.	S.
1	1855	Dec. 1	49.6°	49°	31°	249°	144°	°	°	°	°	8°	4°	8°	8°	4°	0°
2	1855	Dec. 8	49.6	39	88	251	121					8	2	2	3	6	*1*
3	1855	Dec. 4	49.6	54	26	252	154			8	5	9	0	6	0	6	*3*
4	1855	Dec. 10	49.6	56	23	258	152			8	2	6	2	5	1	6	*3*
5	1848	Dec. 20	50.7	54	25	268	139			8	8	2	8				
6	1848	Dec. 21	50.7	54	25	269	139			9		6	5	5	0		
7	1848	Dec. 22	50.7	54	25	270	138			8	3	6	0	5	*1*		
8	1848	Dec. 23	50.7	50	29	271	128			8	8	6	0	4	*1*		
9	1851	Jan. 2	50.7	58	26	282	124			7	5	5	1	4	*1*		
10	1850	Jan. 13	50.7	54	25	293	115			7	2	5	*1*	4	*2*		
11	1855	Jan. 18	49.6	50	30	293	108	10		7	4	5	0	8	*2*		
12	1850	Jan. 14	50.7	56	21	294	119	10		7	2	5	0	4	*2*		
13	1851	Jan. 22	50.7	58	18	302	117	13		7	8	5	0				
14	1851	Jan. 28	50.7	58	18	303	117	15	10	8	3	5	0				
15	1849	Jan. 26	50.7	61	11	806	127			6	5	4	*1*				
16	1851	Jan. 80	50.7	59	15	310	114	11		7	3	4	*1*				
17	1850	Feb. 8	50.7	62	4	319	123	12	6	8	0	4	*2*				
18	1849	Feb. 11	50.7	62	3	322	122			8	1	3	*1*				
19	1851	Feb. 18	50.7	62	3	329	116	13		7	1	4	*3*				
20	1851	Feb. 23	50.7	62	8	334	110	13	6	6	1	8	*1*				
21	1851	Feb. 24	50.7	62	2	335	112	14		7	8	3	*1*				
22	1850	Mar. 5	50.7	62	854	345	114	9	3	3	*1*						
28	1850	Mar. 6	50.7	62	354	346	114	9	9	5	1						
24	1850	Mar. 9	50.7	61	353	349	118	11	6	5	2						
25	1850	Mar. 10	50.7	61	850	350	113	9	5	5	1						
26	1855	Mar. 11	41.9	71	358	351	102			5	0						
27	1855	Mar. 14	41.9	71	354	354	108	9	6	5	0						
28	1850	Mar. 15	50.7	60	349	355	114	8	6	5	2						
29	1855	Mar. 16	41.9	69	848	356	119	8	12	4	*1*						
30	1855	Mar. 18	41.9	70	352	857	108	8	10	3	1						
31	1855	Mar. 19	41.9	71	855	358	102		15	8	5						
32	1850	Mar. 81	50.7	55	337	10	119	7	8	2	1						
88	1851	April 1	50.7	57	340	11	114	9	6	2	1						
84	1855	April 16	40.9	66	342	26	102	12	2								
35	1855	April 17	40.9	66	341	27	102	12	14	6	8						
86	1855	May 5	40.9	59	334	44	103	10	6	5	1						
37	1855	May 6	40.9	53	830	45	115	17		7	8	4	*2*				

TABLE XIII. — MONTHLY MEANS FROM TABLE X.

No.	Month.		No. of Days.	No. of Obs.	Lat. of Obs.	Incl. of Ecl.	Az. of Pole.	Long. of Sun.	Elong. of Zen.	Elongation of Vertex.					
										Stronger.			Diffuse.		
										No.	Sum.	Mean.	No.	Sum.	Mean.
1	1853	April	8	17	19°	89°	345°	18°	109°	15	718°	47°.9	3	226°	75°.3
2	"	June	8	21	26	48	339	94	124	19	1237	65.1	9	978	108.7
3	"	July	8	19	31	40	342	103	125	13	748	57.5	18	1670	92.8
4	"	Aug.	4	5	22	45	359	146	123	3	164	54.7	5	400	80.0
5	"	Sept.	5	18	28	46	13	177	124	6	320	53.3	11	680	61.8
6	"	Oct.	11	34	22	54	22	207	123	15	822	54.8	28	2455	87.7
7	"	Nov.	3	8	22	73	24	225	151	7	589	84.1	7	774	110.6
8	"	Dec.	4	19	22	82	19	276	123	15	1209	80.6	15	1916	127.7
9	1854	Jan.	9	25	24	88	6	297	139	18	1437	79.8	21	2764	131.6
10	"	Feb.	8	22	35	78	1	331	116	22	1754	79.7			
11	"	Mar.	7	16	35	72	342	5	122	12	1027	85.6	6	680	113.3
12	"	April	9	23	35	64	335	32	117	21	1924	91.6	21	2363	112.5
13	"	May	7	17	42	44	328	58	118	16	1416	88.5	16	1870	116.9
14	"	June	5	10	34	39	338	93	130	10	1032	103.2	10	1276	127.6
15	"	July	10	24	25	43	348	117	123	23	2287	99.4	23	2826	122.9
16	"	Aug.	7	17	16	51	0	147	123	17	1518	89.3	6	614	102.3
17	"	Sept.	6	14	28	40	13	174	125	8	591	73.9	4	446	111.5
18	"	Oct.	9	21	32	43	24	202	127	2	155	77.5	14	1364	97.4
19	"	Nov.	4	7	30	56	27	233	123	6	410	68.3	5	439	87.8
20	"	Dec.	13	29	34	66	24	262	129	26	2136	82.2	25	2661	106.4
21	1855	Jan.	11	39	4	104	16	292	118	36	3746	104.1			
22	"	Feb.	7	12	*38*	151	355	322	136	12	1318	109.8			
23	"	Mar.	5	14	*23*	134	346	356	127	8	618	77.2			
24	"	Apr.	8	22	18	85	340	22	125	18	2073	115.2	2	260	130.0

TABLE XIV. — Monthly Means from Table X.

Latitude of Boundaries: Stronger Light.

No.	Elongation 30°						Elongation 60°						Elongation 90°					
	N.			S.			N.			S.			N.			S.		
	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean
1	16	99°	6.2°	16	84°	5.2°	1	3°	3.0°	1	2°	2.0°		°	°		°	°
2	18	486	27.0	2	4	2.0	10	218	21.8	5	47	9.4	2	45	22.5	1	12	12.0
3	11	239	21.7	2	12	6.0	3	44	14.7	3	10	3.3						
4	3	50	16.7															
5	5	89	17.8				1	4	4.0	1	3	3.0						
6	11	213	19.4	4	15	3.8	3	39	13.0	3	28	9.3	2	15	7.5	2	9	4.5
7							4	72	18.0	3	30	10.0	3	24	8.0	3	24	8.0
8	2	32	16.0	2	20	10.0	15	138	9.2	14	123	8.8	3	24	8.0	3	21	7.0
9	2	19	9.5	2	14	7.0	15	124	8.3	15	106	7.1	3	13	4.3	3	11	3.7
10	7	84	12.0	7	51	7.3	20	167	8.4	20	144	7.2	5	17	3.4	5	20	4.0
11	4	39	9.8	4	26	6.5	13	116	8.9	13	67	5.2	6	53	8.8	6	17	2.8
12	2	31	15.5	2	15	7.5	21	230	11.0	21	112	5.3	13	85	6.5	13	19	1.5
13	14	375	26.8				16	203	12.7	15	45	3.0	11	73	6.6	11	32	2.9
14	2	54	27.0				10	169	16.9	10	34	3.4	9	80	8.9	9	24	2.7
15	2	33	16.5	2	5	2.5	22	302	13.7	22	53	2.4	19	175	9.2	19	12	0.6
16	3	50	16.7				16	204	12.8	15	50	3.3	6	41	6.8	6	0	0.0
17	10	233	23.3	3	14	4.7	11	90	8.2	11	18	1.6						
18	12	278	23.2	1	4	4.0	9	51	5.7	2	8	4.0						
19	1	12	12.0				6	29	4.8	6	28	4.7						
20	4	27	6.8				25	165	6.6	25	106	4.2	4	18	4.5	3	11	3.7
21	13	114	8.8	13	145	11.2	35	229	6.5	36	353	9.8	33	120	3.6	33	184	5.6
22				3	65	21.7	9	56	6.2	9	123	13.7	12	18	1.5	12	104	8.7
23				5	64	12.8	11	28	2.5	13	124	9.5						
24	6	69	11.5	7	94	13.4	20	217	10.8	21	203	9.7	19	161	8.5	19	99	5.2

TABLE XV.—MONTHLY MEANS FROM TABLE X.

Latitude of Boundaries: Diffuse Light.

No.	Elongation 60°						Elongation 90°						Elongation 120°					
	N.			S.			N.			S.			N.			S.		
	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean
		°	°		°	°		°	°		°	°		°	°		°	°
1	4	68	17.0	5	23	4.6												
2	9	262	29.1	5	64	12.8	6	174	29.0	4	74	18.5	4	94	23.5	4	81	20.2
3	19	501	26.4	3	52	17.3	11	189	17.2	11	146	13.3						
4	5	122	24.4	3	53	17.7	1	8	8.0	1	6	6.0						
5	6	97	16.1	4	40	10.0												
6	22	648	29.5	3	52	17.3	18	281	15.6	15	239	15.9						
7	1	24	24.0	1	26	26.0	6	177	29.5	7	157	22.4						
8	13	287	22.1	15	319	21.3	15	280	18.7	14	224	16.0	6	85	14.2	6	82	13.7
9	12	273	22.8	12	198	16.5	19	318	16.7	19	273	14.4	17	172	10.1	17	182	10.7
10	15	334	22.3	15	250	16.7	11	166	15.1	15	202	13.5						
11	4	92	23.0	9	119	13.2	6	106	17.7	5	47	9.4						
12	21	463	22.0	2	30	15.0	21	435	20.7	21	248	11.8						
13	16	516	32.2	15	264	17.6	16	451	28.2	16	237	14.8	3	64	21.3	3	28	9.3
14	10	358	35.8	1	18	18.0	10	303	30.3	10	168	16.8	8	160	20.0	8	87	10.9
15	23	805	35.0	2	30	15.0	23	690	30.0	23	338	14.7	15	252	16.8	15	75	5.0
16	12	397	33.1	8	159	19.9	12	282	23.5	9	117	13.0						
17	12	414	34.5	3	32	10.7	4	85	21.2	4	72	18.0						
18	14	437	31.2				13	202	15.5	13	147	11.3						
19	5	148	29.6	5	94	18.8	2	30	15.0	2	22	11.0						
20	22	532	24.2	20	404	20.2	23	412	17.9	23	270	11.7	3	20	6.7	3	23	7.7
21	17	321	18.9	17	386	22.7	17	211	12.4	17	302	17.8	11	76	6.9	12	150	12.5
22				8	235	29.4	7	99	14.1	11	260	23.6				9	150	16.7
23	5	63	12.6	11	295	26.8				9	166	18.4						
24	14	358	25.6	17	405	23.8	14	323	23.1	15	249	16.6	13	273	21.0	15	127	8.5

TABLE XVI. — Monthly Results from Table X.

Stronger Light.

No	Latitude of Axis.									Half Extent in Latitude.								
	Elong. 30°			Elong. 60°			Elong. 90°			Elong. 30°			Elong. 60°			Elong. 90°		
	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean
1	16	7°	0.4°	1	0°	0.0°		°	°	16	91°	5.7°	1	2°	2.0°		°	°
2	2	11	5.5	5	24	4.8	1	4	4.0	2	15	7.5	5	69	13.8	1	16	16.0
3	2	14	7.0	3	17	5.7				2	25	12.5	3	27	9.0			
4																		
5				1	0	0.0							1	4	4.0			
6	4	26	6.5	3	6	2.0	2	3	1.5	4	40	10.0	3	34	11.3	2	12	6.0
7				3	12	4.0	3	0	0.0				3	41	13.7	3	24	8.0
8	2	6	3.0	14	3	0.2	3	2	0.7	2	26	13.0	14	126	9.0	3	22	7.3
9	2	3	1.5	15	8	0.5	3	1	0.3	2	16	8.0	15	115	7.7	3	12	4.0
10	7	16	2.3	20	11	0.5	5	*2*	*0.4*	7	67	9.5	20	153	7.6	5	19	3.8
11	4	7	1.7	13	24	1.8	6	18	3.0	4	33	8.2	13	92	7.1	6	35	5.8
12	2	7	3.5	21	59	2.8	13	33	2.5	2	22	11.0	21	171	8.1	13	50	3.8
13				15	68	4.5	11	20	1.8				15	114	7.6	11	52	4.7
14				10	67	6.7	9	28	3.1				10	101	10.1	9	52	5.8
15	2	14	7.0	22	125	5.7	19	82	4.3	2	19	9.5	22	176	8.0	19	93	4.9
16				15	70	4.7	6	20	3.3				15	119	7.9	6	18	3.0
17	3	27	9.0	11	36	3.3				3	41	13.7	11	53	4.8			
18	1	8	8.0	2	1	0.5				1	12	12.0	2	8	4.0			
19				6	0	0.0							6	29	4.8			
20				25	29	1.2	3	1	0.3				25	133	5.3	3	12	4.0
21	18	*15*	*1.2*	35	*55*	*1.6*	33	*31*	*0.9*	18	128	9.8	35	284	8.1	33	152	4.6
22				9	*33*	*3.7*	12	*42*	*3.5*				9	89	9.9	12	60	5.0
23				11	*35*	*3.2*							11	63	5.7			
24	6	*4*	*0.7*	20	11	0.5	19	30	1.6	6	72	12.0	20	203	10.2	19	127	6.7

TABLE XVII.—Monthly Results from Table X.

Diffuse Light.

No.	Latitude of Axis.									Half Extent in Latitude.								
	Elong. 60°			Elong. 90°			Elong. 120°			Elong. 60°			Elong. 90°			Elong. 120°		
	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean	No.	Sum	Mean
1	4	24°	6.0°		°	°		°	°	4	44°	11.0°		°	°		°	°
2	5	17	3.4	4	16	4.0	4	6	1.5	5	82	16.4	4	90	22.5	4	88	22.0
3	3	10	3.3	11	21	1.9				3	62	20.7	11	165	15.0			
4	3	4	1.3	1	1	1.0				3	58	19.3	1	7	7.0			
5	4	14	3.5							4	54	13.5						
6	2	5	2.5	15	*8*	*0.5*				2	37	18.5	15	228	15.2			
7	1	*1*	*1.0*	6	20	3.3				1	25	25.0	6	155	25.8			
8	13	9	0.7	14	17	1.2	6	1	0.2	13	279	21.5	14	238	17.0	6	84	14.0
9	12	37	3.1	19	24	1.3	17	*4*	*0.2*	12	234	19.5	19	294	15.5	17	177	10.4
10	16	47	2.9	11	12	1.1				16	318	19.6	11	153	13.9			
11	4	18	4.5	5	20	4.0				4	74	18.5	5	67	13.4			
12	2	3	1.5	21	95	4.5				2	33	16.5	21	340	16.2			
13	15	110	7.3	16	107	6.7	3	20	6.7	15	374	24.9	16	345	21.6	3	46	15.3
14	1	7	7.0	10	67	6.7	8	36	4.5	1	25	25.0	10	236	23.6	8	123	15.4
15	2	21	10.5	23	174	7.6	15	86	5.7	2	50	25.0	23	519	22.6	15	163	10.9
16	8	49	6.1	9	45	5.0				8	209	26.1	9	164	18.2			
17	3	31	10.3	4	12	3.0				3	63	21.0	4	77	19.2			
18				13	23	1.8							13	174	13.4			
19	5	26	5.1	2	4	2.0				5	117	23.4	2	26	13.0			
20	20	41	2.0	23	70	3.0	3	*1*	*0.3*	20	445	22.2	23	340	14.8	3	21	7.0
21	17	*33*	*1.9*	17	*50*	*2.9*	11	*32*	*2.9*	17	353	20.8	17	257	15.1	11	108	9.8
22				7	*30*	*4.3*							7	128	18.3			
23	5	*34*	*6.8*							5	97	19.4						
24	14	10	0.7	14	43	3.1	13	76	5.8	14	348	24.9	14	279	19.9	13	192	14.8

TABLE XVIII. — Monthly Results from Table X.

No.	Stronger Light.										Diffuse Light.									
	From 30° to 60°.					From 60° to 90°.					From 60° to 90°.					From 90° to 120°.				
		Displ.		Contr.			Displ.		Contr.			Displ.		Contr.			Displ.		Contr.	
	No.	Sum.	Mean.	Sum.	Mean.	No.	Sum.	Mean.	Sum.	Mean.	No.	Sum.	Mean.	Sum.	Mean.	No.	Sum.	Mean.	Sum.	Mean.
		°	°	°	°		°	°	°	°		°	°	°	°		°	°	°	°
1	1	5	5.0	3	3.0															
2											2	8	4.0	26	13.0	2	*1*	*0.5*	17	8.5
3																				
4																				
5																				
6											1	*2*	*2.0*	12	12.0					
7						1	*4*	*4.0*	5	5.0	1	*1*	*1.0*	12	12.0					
8	2	*6*	*3.0*	10	5.0	2	0	0.0	9	4.5	12	1	0.1	61	5.1	6	*4*	*0.7*	23	3.8
9	2	*3*	*1.5*	7	3.5	1	0	0.0	7	7.0	12	*20*	*1.7*	60	5.0	15	*24*	*1.6*	94	6.3
10	5	*11*	*2.2*	17	3.4	5	*9*	*1.8*	25	5.0	11	*23*	*2.1*	56	5.1					
11	3	0	0.0	15	5.0	6	3	0.5	18	3.0	2	3	1.5	11	5.5					
12	2	*2*	*1.0*	6	3.0	13	*2*	*0.2*	62	4.8	2	9	4.5	*2*	*1.0*					
13						10	*34*	*3.4*	41	4.1	15	*9*	*0.6*	51	3.4	3	*4*	*1.3*	28	9.3
14						9	*35*	*3.9*	41	4.6	1	*2*	*2.0*	5	5.0	8	*23*	*2.9*	73	9.1
15	2	*6*	*3.0*	8	4.0	18	*30*	*1.7*	65	3.6	2	*7*	*3.5*	8	4.0	15	*43*	*2.9*	196	13.1
16						5	*12*	*2.4*	30	6.0	6	*7*	*1.2*	46	7.7					
17	3	*16*	*5.3*	26	8.7															
18																				
19											2	*4*	*2.0*	27	13.5					
20						2	*4*	*2.0*	8	4.0	20	22	1.1	145	7.2	1	2	2.0	14	14.0
21	13	6	0.5	46	3.5	32	26	0.8	123	3.8	17	*17*	*1.0*	96	5.6	11	3	0.3	60	5.5
22						9	12	1.3	40	4.4										
23																				
24	6	8	1.3	25	4.2	19	20	1.1	70	3.7	14	33	2.4	69	4.9	13	35	2.7	69	5.3

TABLE XIX.—Monthly Means from Table XI.

Heis.

No.	Month.	No. of Obs.	Lat. of Obs.	Incl. of Ecl.	Az. of Pole.	Long. of Sun.	Elong. of Zen.	Inner Cone. No.	Inner Cone. Sum.	Inner Cone. Mean.	Outer Cone. No.	Outer Cone. Sum.	Outer Cone. Mean.
			°	°	°	°	°		°	°		°	°
1	January	38	52	55	22	296	120				38	3359	88.4
2	February	44	52	61	4	326	118				44	3730	84.8
3	March	51	52	60	354	354	114	1	45	45.0	51	3495	68.5
4	April	30	52	51	332	23	113				30	2107	70.2
5	May	3	52	40	322	44	118				3	215	71.7
6	July	1	52	21	35	119	212				1	94	94.0
7	August	1	52	22	87	137	198				1	96	96.0
8	November	1	52	43	85	238	149				1	85	85.0
9	December	16	52	47	82	265	130				16	1341	83.8

Weber.

No.	Month.	No. of Obs.	Lat. of Obs.	Incl. of Ecl.	Az. of Pole.	Long. of Sun.	Elong. of Zen.	Inner Cone. No.	Inner Cone. Sum.	Inner Cone. Mean.	Outer Cone. No.	Outer Cone. Sum.	Outer Cone. Mean.
1	January	14	52	58	17	299	122	2	169	84.5	14	1209	86.4
2	February	19	52	61	4	326	116	4	306	76.5	19	1692	89.1
3	March	26	52	60	349	356	112	2	134	67.0	26	2210	85.0
4	April	21	52	52	338	25	108	2	145	72.5	21	1839	87.6
5	May	2	52	45	326	42	108				2	181	90.5
6	December	5	52	42	87	261	119				5	509	101.8

(Elongation of Vertex: Inner Cone and Outer Cone.)

TABLE XX.—Monthly Means from Table XI.

Latitude of Boundaries.

Heis.

No	Elongation 30° N No.	Sum.	Mean.	Elongation 30° S. No.	Sum.	Mean.	Elongation 60° N. No.	Sum.	Mean.	Elongation 60° S. No.	Sum.	Mean.	Elongation 90° N. No.	Sum.	Mean.	Elongation 90° S. No.	Sum.	Mean.
		°	°		°	°		°	°		°	°		°	°		°	°
1	12	272	22.7	7	84	12.0	37	539	14.6	37	332	9.0	11	59	5.4	11	39	3.5
2	10	224	22.4	8	112	14.0	44	629	14.3	44	373	8.5	4	26	6.5	4	1	0.2
3	40	863	21.6	38	445	11.7	39	373	9.6	39	208	5.2	2	9	4.5	2	2	1.0
4	20	422	21.1	17	210	12.4	23	229	10.0	23	127	5.5						
5	2	42	21.0				3	33	11.0	3	15	5.0						
6	1	48	48.0				1	32	32.0				1	12	12.0			
7							1	18	18.0	1	4	4.0						
8							1	8	8.0	1	2	2.0						
9	7	191	27.3	6	49	8.2	16	254	15.9	16	95	5.9	2	17	8.5	2	7	3.5

Weber.

No	Elongation 30° N No.	Sum.	Mean.	Elongation 30° S. No.	Sum.	Mean.	Elongation 60° N. No.	Sum.	Mean.	Elongation 60° S. No.	Sum.	Mean.	Elongation 90° N. No.	Sum.	Mean.	Elongation 90° S. No.	Sum.	Mean.
1	8	69	23.0	8	27	9.0	14	193	13.8	14	109	7.8						
2	9	213	23.7	9	139	15.4	19	224	11.8	19	123	6.5	2	7	3.5	2	2	1.0
3	17	360	21.2	17	242	14.2	26	259	10.0	26	171	6.6	5	18	3.6	5	15	3.0
4	6	120	20.0	5	63	12.6	20	253	12.6	20	153	7.6	5	44	8.8	5	15	3.0
5	1	18	18.0	1	14	14.0	2	31	15.5	2	8	4.0						
6							4	58	14.5	4	50	12.5	4	38	9.5	4	26	6.5

TABLE XXI. — MONTHLY RESULTS FROM TABLE XI.

No.	Latitude of Axis.									Half Extent in Latitude.								
	Elong. 30°			Elong. 60°			Elong. 90°			Elong. 30°			Elong. 60°			Elong. 90°		
	No.	Sum.	Mean.	No.	Sum.	Mean.	No.	Sum.	Mean.	No.	Sum.	Mean.	No	Sum.	Mean.	No.	Sum.	Mean.
HEIS.																		
1	7	38°	5.4°	37	100°	2.7°	14	11°	0.8°	7	121°	17.3°	37	436°	11.8°	11	49°	4.5°
2	8	29	3.6	44	124	2.8	10	18	1.8	8	141	17.6	44	501	11.4	4	14	3.5
3	38	185	4.9	41	91	2.2	3	3	1.0	38	630	16.6	39	287	7.4	2	5	2.5
4	17	69	4.1	26	56	2.2				17	280	16.5	23	176	7.7			
5				3	9	3.0							3	24	8.0			
6																		
7				1	7	7.0							1	11	11.0			
8				1	3	3.0							1	5	5.0			
9	6	66	11.0	16	77	4.8	4	17	4.2	6	116	19.3	16	174	10.9	2	12	6.0
WEBER.																		
1	3	21	7.0	14	43	3.1	4	6	1.5	3	48	16.0	14	151	10.8			
2	9	36	4.0	19	49	2.6	5	8	1.6	9	174	19.3	19	173	9.1	2	4	2.0
3	17	54	3.2	26	47	1.8	7	4	0.6	17	306	18.0	26	214	8.2	5	17	3.4
4	5	21	4.2	21	51	2.4	5	15	3.0	5	83	16.6	20	202	10.1	5	30	6.0
5	1	2	2.0	2	11	5.5				1	16	16.0	2	19	9.5			
6				4	3	0.8	4	7	1.8				4	55	13.7	4	32	8.0

TABLE XXII. — MONTHLY RESULTS FROM TABLE XI.

No.	From 30° to 60°						From 60° to 90°					
	Displ.			Contr.			Displ.			Contr.		
	No.	Sum.	Mean.	No.	Sum.	Mean.	No.	Sum.	Mean.	No.	Sum.	Mean.
HEIS.												
1	7	*11°*	*1.6°*	7	56°	8.0°	13	*25°*	*1.9°*	10	100°	10.0°
2	8	*16*	*2.0*	8	70	8.8	10	*12*	*1.2*	4	48	12.0
3	28	*89*	*3.2*	26	293	11.3	3	*3*	*1.0*	2	20	10.0
4	13	*33*	*2.5*	10	108	10.8						
5												
6												
7												
8												
9	6	*20*	*3.3*	6	49	8.2	4	0	0.0	2	13	6.5
WEBER.												
1	3	*8*	*2.7*	3	25	8.3	4	*1*	*0.2*			
2	9	*9*	*1.0*	9	95	10.6	5	*1*	*0.2*	2	15	7.5
3	17	*20*	*1.2*	17	174	10.2	7	0	0.0	5	42	8.4
4	5	*7*	*1.4*	4	37	9.2	5	*2*	*0.4*	5	38	7.6
5	1	2	2.0	1	13	13.0						
6							3	*1*	*0.3*	3	29	9.7

TABLE XXIII. — Results from Table X.

Stronger Light.

Group.	Incl. of Ecl.	Elong. of Zen.	Elongation of Vertex.		Latitude of Boundaries.											
					N. Elong. 30° S.				N. Elong. 60° S.				N. Elong. 90° S.			
			No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.
1	43°	125°	100	79.5°	77	23.9°	10	3.9°	82	13.2°	69	3.2°	41	9.1°	40	2.0°
2	53	123	38	72.4	15	18.3	4	3.8	25	10.9	24	4.4	8	7.0	8	1.1
3	65	124	47	86.4	6	9.7	2	7.5	46	8.6	46	4.7	17	6.1	16	1.9
4	79	124	74	89.9	19	11.8	20	9.6	72	9.9	71	8.0	36	7.8	36	5.0
5	88	127	83	65.3	18	6.6	18	5.4	16	7.9	16	6.8	3	4.3	3	3.7
6	104	118	86	104.1	18	8.8	13	11.2	35	6.5	36	9.8	33	3.6	33	5.6
7	142	131	20	96.8			8	16.1	20	4.2	22	11.2	12	1.5	12	8.7

TABLE XXIV. — Results from Table X.

Diffuse Light.

Group.	Lat. of Obs.	Z. D. of Sun.	Elongation of Vertex.		Latitude of Boundaries.											
					N. Elong. 60° S.				N. Elong. 90° S.				N. Elong. 120° S.			
			No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.
1	30°	113°	110	104.6°	114	30.8°	36	15.4°	84	25.0°	82	14.5°	30	19.0°	30	9.0°
2	21	116	89	89.9	39	30.6	16	19.1	32	18.5	26	14.5				
3	34	121	46	109.2	43	23.1	22	19.7	44	19.2	44	11.7	3	6.7	3	7.7
4	27	123	80	121.0	47	23.8	57	19.6	52	20.2	56	15.7	19	18.8	21	10.0
5	22	127	24	124.6	16	21.3	17	13.0	19	16.7	19	14.4	17	10.1	17	10.7
6	4	117			17	18.9	17	22.7	17	12.4	17	17.8	11	6.9	12	12.5
7	*30*	114			5	12.6	19	27.9	7	14.1	20	21.3			9	16.7

TABLE XXV. — Results from Table X.

Stronger Light.

Group.	Elong. 30°			Elong. 60°			Elong. 90°			From 30° to 60°			From 60° to 90°		
	No.	Axis.	Ext.	No.	Axis.	Ext.	No.	Axis.	Ext.	No.	Displ.	Contr.	No.	Displ.	Contr.
1	10	7.4°	11.2°	69	4.9°	8.0°	40	3.4°	5.8°	5	*4.4*°	6.8°	37	*2.7*°	4.0°
2	4	6.5	10.0	24	3.2	7.6	8	2.9	3.7				5	*2.4*	6 0
3	2	3.5	11 0	46	1.9	6.6	16	2.1	3.9	2	*1.0*	3.0	15	*0.4*	4.7
4	19	1.3	10.4	70	0.9	8.8	36	1.3	6.3	16	*0 6*	4 2	33	0.3	3.8
5	18	0.6	5.9	16	0.5	7.3	3	0.3	4.0	3	0.7	3.3	1	0 0	7.0
6	13	*1.2*	9.8	35	*1 6*	8.1	33	*0.9*	4.6	13	0.5	3.5	32	0.8	3.8
7				20	*3.4*	7.6	12	*3.5*	5.0				9	1.3	4.4

TABLE XXVI. — Results from Table X.

Diffuse Light.

Group.	Elong. 60°			Elong. 90°			Elong. 120°			From 60° to 90°			From 90° to 120°		
	No.	Axis.	Ext.	No.	Axis.	Ext.	No.	Axis.	Ext.	No.	Displ.	Contr.	No.	Displ.	Contr.
1	86	5°.9	21°.3	82	5°.1	19°.7	30	4°.9	14°.0	20	*0°.5*	4°.5	28	*2°.5*	11°.2
2	15	5.3	24.2	26	1.6	16.1				9	*1.4*	9.4			
3	22	2.0	21.7	44	3.8	15.5	3	*0.3*	7.0	22	1.4	6.5	1	2.0	14.0
4	48	1.7	21.6	50	2.2	17.8	19	4.1	14.5	40	8.2	5.2	19	1.6	4.8
5	16	3.8	17.4	19	1.3	15.5	17	*0.2*	10.4	12	*1.7*	5.0	15	*1.6*	6.3
6	17	*1.9*	20.8	17	*2.9*	15.1	11	*2.9*	9.8	17	*1.0*	5.6	11	0.3	5.5
7	5	*6.8*	19.4	7	*4.3*	18.3									

TABLE XXVII. — Results from Table XI.

Group.	Incl. of Ecl.	Elong. of Zen.	Elongation of Vertex.		Latitude of Boundaries.											
					N. Elong. 30°		S.		N. Elong. 60°		S.		N. Elong. 90°		S.	
			No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean	No.	Mean	No.	Mean.
Heis.																
1	46°	129°	20	82°.0	9	25°.9	6	8°.2	20	14°.8	20	5°.6	2	8°.5	2	3°.5
2	53	117	68	80.4	32	21.7	24	12.2	60	12.8	60	7.6	11	5.4	11	3.5
3	60	116	95	76.1	50	21.7	46	12.1	83	12.1	83	6.9	6	5.8	6	0.5
Weber.																
1	43	116	7	98.6	1	18.0	1	14.0	6	14.8	6	9.7	4	9.5	4	6.5
2	54	114	35	87.1	9	21.0	8	11.2	34	13.1	34	7.7	5	8.8	5	8.0
3	60	114	45	86.7	26	22.0	26	14.7	45	10.7	45	6.5	7	3.6	7	2.4

TABLE XXVIII. — Results from Table XI.

Group.	Elong. 30°				Elong. 60°				Elong. 90°				From 30° to 60°				From 60° to 90°			
	No.	Axis.	No.	Ext.	No.	Axis.	No.	Ext.	No.	Axis.	No.	Ext.	No.	Displ.	No.	Contr.	No.	Displ.	No.	Contr.
Heis.																				
1	6	11°.0	6	19°.8	20	4°.4	20	10°.2	4	4°.2	2	6°.0	6	*3°.3*	6	8°.2	4	0°.0	2	6°.5
2	24	4.5	24	16.7	63	2.5	60	10.2	14	0.8	11	4.5	20	*2.2*	17	9.6	13	*1.9*	10	10.0
3	46	4.7	46	16.8	85	2.5	88	9.5	13	1.6	6	3.2	36	*2.9*	34	10.7	13	*1.2*	6	11.3
Weber.																				
1	1	2.0	1	16.0	6	2.3	6	17.3	4	1.8	4	8.0	1	2.0	1	13.0	3	*0.3*	3	9.7
2	8	5.2	8	16.4	35	2.7	34	1[illegible].4	9	2.3	5	6.0	8	*1.9*	7	8.9	9	*0.3*	5	7.6
3	26	3.5	26	18.5	45	2.1	45	[illegible].6	12	1.0	7	3.0	26	*1.1*	26	10.3	12	*0.1*	7	8.1

TABLE XXIX. — Results from Table XI.: Eylert and Neumayer.

Group.	Incl. of Ecl.	Elong. of Zen.	Elongation of Vertex.		Latitude of Boundaries.											
					N. Elong. 30° S.				N. Elong. 60° S.				N. Elong. 90° S.			
			No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.
1	63°	120°	3	90.0°	8	13.7°	2	6.5°	5	11.8°	5	5.8°	3	5.7°	3	4.3°
2	77	119	1	70.0	1	15.0	1	15.0	3	8.7	3	3.0	2	7.5	2	*1.0*
3	91	118	6	83.3	4	23.5	4	13.5	7	6.3	7	5.8				
4	104	111	8	68.8	8	13.6	8	15.6	8	3.0	8	6.0				

TABLE XXX. — Results: Eylert and Neumayer.

Group.	Lat. of Obs.	Z. D. of Sun.	Elong. Vert. Inner Cone.		Latitude of Boundaries.											
					N. Elong. 120° S.				N. Elong. 150° S.				N. Elong. 180° S.			
			No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.
1	30°	117°		°	2	*7.5*°	2	16.5°		°		°		°		°
2	15	118			2	*1.0*	2	9.0	2	*12.5*	2	18.0	2	*17.5*	2	24.5
3	*11*	118	1	53.0												
4	*31*	110	8	55.7												

TABLE XXXI. — Results: Eylert and Neumayer.

Group.	Elong. 30°			Elong. 60°			Elong. 90°			From 30° to 60°			From 60° to 90°		
	No.	Axis.	Ext.	No.	Axis.	Ext.	No.	Axis.	Ext.	No.	Displ.	Contr.	No.	Displ.	Contr.
1	2	6.5°	12.5°	5	3.0°	8.6°	3	0.3°	4.7°	2	*1.0*°	6.0°	3	*1.0*°	5.3°
2	1	0.0	15.0	3	2.7	6.0	2	4.0	3.0	1	6.0	10.0	2	3.0	3.5
3	4	5.2	18.7	7	0.6	5.7				4	*3.0*	14.5			
4	8	*0.9*	14.8	9	*1.2*	4.0				8	*0.2*	10.1			

TABLE XXXII. — Results: Eylert and Neumayer.

Group.	Elong. 120°			Elong. 150°			Elong. 180°			From 90° to 120°			From 120° to 150°		
	No.	Axis.	Ext.	No.	Axis.	Ext.	No.	Axis.	Ext.	No.	Displ.	Contr.	No.	Displ.	Contr.
1	2	*11.5*°	10.0°		°	°		°	°	2	*11.0*°	*5.5*°		°	°
2	2	*5.0*	4.0	2	*15.0*	2.8	2	*21.0*	8.5	2	*9.0*	*1.0*	2	*10.0*	1.2
3															
4															

TABLE XXXIII. — Results from Table XII.

Group.	Lat. of Obs.	Incl. of Ecl.	Elong. of Zen.	Z. D. of Sun.	Latitude of Boundaries.															
					N. Elong. 30° S.				N. Elong. 60° S.				N. Elong. 90° S.				N. Elong. 120° S.			
					No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.	No.	Mean.
1	50°	47°	124°	114°	1	10.0°		°	2	7.5°	2	8.5°	4	6.8°	4	1.5°	4	3.0°	4	0.8°
2	50	55	130	121	4	10.8	2	7.0	11	6.6	10	2.7	9	5.8	9	1.4	7	4.7	7	*0.7*
3	50	61	116	112	13	11.3	9	6.3	15	6.1	15	1.7	9	8.9	9	*1.1*				
4	42	69	106	105	5	9.8	6	9.8	6	4.3	6	1.3								

TABLE XXXIV. — Results from Table XII.

Group.	Elong. 30°			Elong. 60°			Elong. 90°			Elong. 120°			From 30° to 60°			From 60° to 90°			From 90° to 120°		
	No.	Axis.	Ext.	No.	Axis.	Ext.	No.	Axis.	Ext.	No.	Axis.	Ext.	No.	Displ.	Contr.	No.	Displ.	Contr.	No.	Displ.	Contr.
1		°	°	2	2.0°	5.5°	4	2.5°	4.0°	4	1.5°	2.2°		°	°	2	0.5°	8.0°	4	*1.0°*	1.8°
2	2	0.5	7.5	10	2.0	4.4	9	1.8	3.3	7	2.4	2.1	2	1.0	6.0	8	*0.1*	2 1	7	0.1	1.3
3	9	2.0	8.4	15	2.1	4.0	9	2.1	1.6				9	0.1	5.0	9	*0.2*	3.2			
4	5	0.6	9.2	6	1.3	2.7							4	2.2	7.2						

TABLE XXXV. — Atmospheric Absorption.

Z. D.	Abs.	Z. D.	Abs.	Z. D.	Abs.	Z. D.	Abs.	Z. D.	Abs.	Z. D.	Abs.
17°	0.01	29°	0.03	41°	0.07	53°	0.15	65°	0.32	77°	0.76
18	0.01	30	0.03	42	0.07	54	0.16	66	0.34	78	0.82
19	0.01	31	0.03	43	0.08	55	0.17	67	0.36	79	0.90
20	0.01	32	0.03	44	0.08	56	0.18	68	0.39	80	0.98
21	0.01	33	0.04	45	0.09	57	0.19	69	0.42	81	1.07
22	0.01	34	0.04	46	0.09	58	0.20	70	0.45	82	1.18
23	0.01	35	0.04	47	0.10	59	0.22	71	0.48	83	1.32
24	0.02	36	0.05	48	0.11	60	0.23	72	0.52	84	1.49
25	0.02	37	0.05	49	0.11	61	0.25	73	0.56	85	1.72
26	0.02	38	0.05	50	0.12	62	0.26	74	0.60	86	2.04
27	0.02	39	0.06	51	0.13	63	0.28	75	0.65	87	2.48
28	0.02	40	0.06	52	0.14	64	0.30	76	0.70	88	3.10

VI.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON CERTAIN SUBSTANCES OBTAINED FROM TURMERIC.

By C. Loring Jackson and A. E. Menke.

Presented May 29, 1883.

Owing to the difficulty of preparing curcumin, and the very unmanageable nature of the products obtained from it and from turmerol, we have not made as much progress in the study of these substances as we had hoped. In fact, we should not publish our results at the present time, were it not that we cannot continue the work together at all, and neither of us will be able to return to it for at least a year; we have therefore decided to collect in the following papers all the results we have obtained up to this time, although many of them are very fragmentary, and others consist only in indications which may prove useful in future work.

IV. CURCUMIN.

Action of Acetic Anhydride on Curcumin.

Monacetcurcumin. $C_{14}H_{13}(C_2H_3O)O_4$. This substance is formed by the action of acetic anhydride and fused sodic acetate on curcumin, probably also by the action of acetylchloride. As has been stated in a previous paper,* it forms an uninviting brown resin, which we have not as yet succeeded in bringing into a crystalline condition; but nevertheless it can be obtained in a state of purity by the following method: Curcumin is heated on the water-bath with a slight excess of acetic anhydride and a little fused sodic acetate, for about sixteen hours, in a flask with a return-cooler; the dark brown viscous product is then dissolved in a little glacial acetic acid, and precipitated with water; after repeating the solution in acetic acid, and precipitation

* These Proceedings, Vol. XVII. p. 123.

with water, the yellowish-brown precipitate is washed until free from acetic acid, and dried *in vacuo*.

0.1710 gr. of substance gave 0.4178 gr. of carbonic dioxide and 0.0922 gr. of water.

	Calculated for $C_{16}H_{16}O_5$.	Found.
Carbon	66.67	66.62
Hydrogen	5.55	5.99

Properties. A viscous brown mass without definite melting-point, although it shrinks together at 58°–60°, but it does not become fully liquid below 100°. It is soluble in alcohol and glacial acetic acid, essentially insoluble in ligroine and carbonic disulphide, slightly soluble in ether and in benzol; but its solubility in the latter is greater than that of curcumin. It dissolves in strong sulphuric acid with a blood-red color like that produced by curcumin. Aqueous sodic hydrate dissolves it, forming a red solution, which becomes decomposed, with the formation of ill-defined black products, when allowed to stand exposed to the air; a mixture of alcohol and sodic carbonate was reddened instantly by the substance, showing that the acetyl group had replaced the hydrogen of the phenol hydroxyl, as was to be expected; that is, its formula would be

$$C_6H_3(\overset{3}{O}CH_3)(O\overset{4}{C_2}H_3O)(C_6H_6\overset{1}{C}OOH).$$

As has been stated already,* the substance gave unsatisfactory results when submitted to oxidation with potassic permanganate.

Diacetcurcumin. $C_{14}H_{12}(C_2H_3O)_2O_4$. On one occasion the process described above yielded a yellow crystalline product instead of the brown viscous monacetcurcumin. The coming of the vacation interrupted our work before we had succeeded in determining the conditions on which the formation of this substance depends, the few experiments which we had time to try giving invariably monacetcurcumin; we must therefore, for the present, confine ourselves to describing the properties and analysis of the substance. After the removal of the acetic anhydride and sodic acetate by treatment with water, it was purified by washing with alcohol and crystallization from glacial acetic acid, dried at 100°, and analyzed.

0.2230 gr. of substance gave 0.5348 gr. of carbonic dioxide and 0.1090 gr. of water.

	Calculated for $C_{18}H_{18}O_6$.	Found.
Carbon	65.45	65.39
Hydrogen	5.45	5.43

* These Proceedings, Vol. XVII. p. 128.

Properties. It crystallizes from glacial acetic acid in rosettes of a vivid yellow color without the orange shade of curcumin, which are made up of very characteristic rhombic plates; melting-point, 154°. It is more soluble in glacial acetic acid than in any other solvent, especially when the acid is hot; less soluble in alcohol than curcumin; slightly soluble in ether and benzol; essentially insoluble in ligroine and carbonic disulphide. Strong sulphuric acid dissolves it, becoming blood-red in transmitted light, green like rosanilin in reflected light; the red color is somewhat more purple than that produced by curcumin. Sodic hydrate in aqueous solution acts upon it very slowly, and not rapidly, even if dissolved in dilute alcohol; the red solution thus obtained gives with hydrochloric acid a viscous brown mass with a low melting-point, which seems to be impure monacetcurcumin. Sodic carbonate and alcohol give an orange solution looking like that of potassic dichromate. According to the formula given by us to curcumin in our first paper, this substance should be a mixed anhydride of curcumin and acetic acid, with the other acetyl group attached to the phenol oxygen, as in the monacet-compound, — a constitution which would be expressed by the following formula: —

$$C_6H_3(OCH_3)(OC_2H_3O)(C_6H_6COOC_2H_3O).$$

That the carboxyl group is affected by the introduction of the second acetyl is shown by the fact that alkaline reagents act upon it only after some time, and then evidently decompose it; whereas the monacet-compound is attacked by them instantly, and the action consists only in the formation of a salt: but, on the other hand, the substance is more stable than acid anhydrides are usually, as is shown by this very action with alkalies, and by the fact that it can be boiled with water for many hours without undergoing any change in melting-point, or the formation of any soluble acid.

Action of Phosphoric Oxychloride on Curcumin.

Of all the reactions of curcumin, which we have observed, this is by far the most striking, and we have decided therefore to describe it at some length, although we have not succeeded in determining the nature of the substance formed. If a few drops of phosphoric oxychloride are added to some curcumin suspended in ligroine, its orange-yellow color is converted instantly into a rich reddish purple, which in reflected light appears bronze-green with a metallic lustre, between the colors of rosanilin and Hofmann's violet. To prepare the substance in quantity, the curcumin was rubbed in a mortar with phosphoric

oxychloride diluted with ligroine and afterward washed repeatedly with ligroine; the dark purple viscous mass thus obtained was dried in a desiccator over sulphuric acid, lime, and paraffine. This treatment, the best which we could devise, was usually far from effectual, as in every case but one the substance contained phosphorus, and was invariably converted during drying into a black mass having very different properties from the purple viscous substance at first obtained. The analysis of the substance free from phosphorus gave results less than one per cent higher than those required by curcumin, and this was confirmed by the analysis of one of the preparations containing phosphorus, after the phosphorus present had been calculated as phosphoric acid, and subtracted from the weight of the substance.

The properties of the purple product are quite as striking as its formation from curcumin; for the addition of water converts it again into curcumin, and the change from purple to orange-yellow is instantaneous. That curcumin was formed in this case was shown by the melting-point, 178°. Alcohol also changes the color instantly from purple to yellow; but the product is much more soluble in alcohol than curcumin, and is possibly its ethylether. Ether acts in the same way, leaving, on evaporation, a viscous red mass; in ligroine and benzol it is essentially insoluble. By standing even in desiccator it is gradually decomposed — more rapidly at 100° — into a black mass, which is unaffected by water, but soluble in alcohol, or sodic hydrate forming dark solutions. Owing to the uninviting properties of this decomposition-product it was not studied further.

It is highly probable that the blood-red color imparted to strong sulphuric acid by curcumin is due to this substance, as curcumin is deposited when this solution is diluted. As to the nature of the purple substance, our analyses show nothing; but its easy conversion into curcumin by the addition of water indicates that it is an anhydride, and we are inclined to believe that the carboxyl of the curcumin alone is involved in the reaction, because we obtained a similar but somewhat redder color when monacetcurcumin was treated with phosphoric oxychloride.

In our first paper on curcumin we assigned to it the formula

$$C_6H_3(OH)(OCH_3)(C_6H_6COOH).$$

Our work since then has been directed toward the determination of the structure of the side-chain C_6H_6COOH, and, although we have

not succeeded in proving anything about it definitely, we may be allowed to state that our results can be explained by the assumptions that the carboxyl is attached to the carbon atom next but one to the benzol ring, and that in the remainder of the side-chain some of the carbon atoms are united to form a ring.

TURMEROL.

In our first paper on this subject we mentioned that, although turmerol is converted into terephthalic acid by treatment with an excess of a hot solution of potassic permanganate, the same reagent produces, when cold and not in excess, one or more apparently new acids. In the following paper we describe our study of the product of this reaction, a complex mixture of acids, from which we have succeeded in isolating two new acids, — one having the formula $C_{11}H_{14}O_2$, which we propose to call turmeric acid, the other either $C_{10}H_{12}O_4$ or $C_{10}H_{10}O_4$, to which we would give the name apoturmeric acid.

In order to obtain this product, a little turmerol was allowed to stand at ordinary temperatures with a moderately strong solution of potassic permanganate until the latter was reduced. The operation was carried on in large beakers, and the yield seemed to be better when not more than 500 c.c. of permanganate solution were used in each oxidation, than when larger quantities were employed; with this amount the action came to an end in about three days. After the liquid had become colorless, the oxide of manganese and unaltered oil were removed by filtration, and again treated with permanganate solution; this treatment being repeated until the permanganate ceased to act, when it was found that the oxide of manganese was essentially free from organic matter, and therefore that the entire product was contained in the aqueous filtrate. The mixed filtrates from a number of operations were then concentrated on the water-bath, acidified with sulphuric acid, extracted several times with ether, and the extract, a black tarry liquid, distilled with steam, when a yellow oil (A) passed over with some difficulty; this was mostly turmeric acid. The residue in the flask (B) contained a tarry substance and apoturmeric acid, which not infrequently separated in white crystals as the solution cooled.

Upon distilling with steam the solution left after extraction with ether, it yielded a strongly acid distillate containing a little of the yellow oily acid, from which it was freed in great part by extracting it five times with ether. It was then boiled with baric carbonate to convert it into a barium salt, which crystallized, after it had evapo-

rated spontaneously nearly to dryness; the crystals, freed from mother-liquor by pressure between filter-paper, were nearly pure baric acetate, as shown by the following analysis: —

1.1745 gr. of the air-dried salt lost 0.0661 gr. when dried at 100°.

	Calculated for $Ba(C_2H_3O_2)_2H_2O$.	Found.
Water	6.59	5.63

1.1038 gr. of the dried salt gave 0.9974 gr. of baric sulphate.

	Calculated for $Ba(C_2H_3O_2)_2$.	Found.
Barium	53.73	53.13

As, however, a solution of the silver salt blackened much more easily than argentic acetate should, and crystallized at first in balls made up of radiating needles, although after one or two recrystallizations attended by blackening it gave the flattened needles characteristic of argentic acetate, we suspected that there might be some other acid present, the barium salt of which had been removed in the mother-liquors, and resorted to fractional acidification with sulphuric acid to settle this point. For this purpose a quantity of the acid distillate, after treatment with ether, was converted into the calcium salt and treated with one third of the amount of sulphuric acid necessary to set free all the acid it contained; it was then distilled with steam as long as the distillate showed an acid reaction. The residue in the flask was treated twice successively with the same amounts of sulphuric acid, and the first and third fractional distillates converted into calcium salts.

I. 0.3582 gr. of salt from the first fraction gave 0.2894 gr. of calcic sulphate.

II. 0.2281 gr. of salt from the third fraction gave 0.1980 gr. of calcic sulphate,

	Calculated for $Ca(C_2H_3O_2)_2$.	Found. I.	Found. II.	Calculated for $Ca(C_3H_5O_2)_2$.
Calcium	25.32	23.76	25.54	21.50

From these numbers it appears that there is no large amount of any acid except acetic present, and the blackening and different crystalline forms of the silver salt were probably due to a trace of turmeric acid which could not be removed by ether.

As it was possible that a neutral lactone might have been formed, a portion of the acid liquid was boiled with baric carbonate, distilled with steam, and the neutral distillate boiled with baric hydrate for some time; as after removing the baric hydrate with carbonic dioxide there was no residue on evaporation no lactone was formed.

The formation of carbonic dioxide was determined by a special experiment, in which a portion of turmerol was oxidized out of contact with the air; upon acidifying with sulphuric acid a gas was given off, which gave a copious white precipitate with lime-water.

A. *Study of the Distillate obtained from the Ether Extract with Steam.*

This consisted principally of water, with a few yellow or brown oil-drops floating in it. It was extracted with ether, and the extract, which had acid properties, boiled with water and calcic carbonate. The solution of a calcium salt thus obtained, when allowed to evaporate spontaneously, deposited spherical collections of white needles and a yellow viscous substance somewhat more soluble than the crystals.

The crystalline body proved to be the calcium salt of the new acid, which we have called turmeric acid, after it had been purified by repeated crystallization from water, which is tedious in the highest degree, as all the solutions and evaporations have to be carried on at ordinary temperatures; in fact, it took us more than a year and a half to prepare and purify the four or five grammes of this substance, which have served for the present research.

In regard to the nature of the viscous non-crystalline salt we cannot speak with certainty, as we were unable to obtain it free from calcic turmerate; but we are of the opinion that it is a salt of an isomeric acid, as an analysis of the salt, which had not been purified by crystallization, gave 8.12 per cent of calcium instead of 8.93 calculated for calcic turmerate, and the acid set free from the amorphous salt remained liquid even at $-5°$, while turmeric acid solidifies at ordinary temperatures.

The total yield of mixed calcium salts cannot be more than one or two per cent of the turmerol oxidized, and the proportion of amorphous salt in this product is comparatively small.

Turmeric Acid. $C_{11}H_{14}O_2$. The calcium salt prepared and purified as just described was treated with hydrochloric acid, and then extracted with ether. On evaporating off the ether, a yellowish oil was left, which crystallized on standing, and gave the following analytical results after being dried *in vacuo:* —

I. 0.2198 gr. of substance gave 0.5954 gr. of carbonic dioxide and 0.1586 gr. of water.

II. 0.1320 gr. gave 0.3584 gr. of carbonic dioxide and 0.0960 gr. of water.

	Calculated for $C_{11}H_{14}O_2$.	Found. I.	II.
Carbon	74.16	73.87	74.04
Hydrogen	7.86	8.02	8.08

Properties. The turmeric acid, as at first precipitated, is an oil, which gradually solidifies in long white branching needles, or crystalline masses with a faint smell like cocoanut; freed from oil by pressing between filter-paper it melts at 34°–35°; it is slightly soluble in water, very freely in all the other common solvents except methyl-alcohol, in which, however, it is readily soluble, so that it was found impossible to crystallize it from this or any other solvent; it distils slowly with steam, and is a monobasic acid. When oxidized with a hot solution of potassic permanganate, not in too great excess, it gives the apoturmeric acid, which will be described later in this paper.

Calcic Turmerate. $Ca(C_{11}H_{13}O_2)_2 . 3H_2O$. The preparation and purification of this salt have been described in connection with the manufacture of turmeric acid. For analysis it was dried, at first *in vacuo*, and afterward at 100° or 110°, when several agreeing analyses gave the percentage of calcium 10.78–11.13, whereas calcic turmerate contains only 10.15 per cent of calcium. This led us to suspect that the salt had undergone a constant decomposition at this temperature, which we were the more inclined to do, because at first it lost weight very rapidly, but later the loss dropped to a few milligrammes a day, and more than a week of continuous heating was necessary to obtain a constant weight, while at the same time the salt gradually became brown and viscous. We have therefore calculated our results upon the salt dried *in vacuo*, and these agree very well with the amount of calcium in calcic turmerate containing three molecules of water of crystallization.

I. 0.3131 gr. of substance dried *in vacuo* gave 0.0970 gr. of calcic sulphate.

II. 0.2993 gr. gave 0.0912 gr. of calcic sulphate.

	Calculated for $Ca(C_{11}H_{13}O_2)_2 3H_2O$.	Found. I.	II.
Calcium	8.93	9.11	8.96

Properties. It forms spherical collections of white radiating needles looking like chestnut-burs; the purer the salt the more distinct are the separate needles. When boiled with water it melts to a viscous mass, which is then acted on by the water only very slowly; it is therefore advisable to dissolve it in the cold.

7.861 gr. of the solution saturated at 16° gave 0.0344 gr. of calcic sulphate. Therefore a saturated solution at 16° contains 1.27 per cent of $Ca(C_{11}H_{13}O_2)_2$.

The salt is also soluble in alcohol, and is decomposed by a heat of 100°–110°, as already stated.

The behavior of a solution of the calcium salt with various reagents was also studied, and it was found to give a white flocculent precipitate with aluminic chloride; a similar reddish-brown precipitate with ferric chloride; heavy white precipitates with mercurous or plumbic salts, the plumbic salt melting under boiling water and forming, when prepared in quantity, an uninviting yellowish viscous mass; cupric nitrate produced pale-blue flocks, and argentic nitrate a heavy white precipitate somewhat soluble in water; the other common reagents gave no characteristic precipitates.

An attempt was made to prepare and analyze the *silver salt*, but we did not succeed in purifying it, since its solubility in water is so great that the impurities could not be removed by washing without using a larger amount of substance than was at our disposal; and it was impossible to recrystallize it from water, as its solutions decomposed with great ease. An imperfectly washed specimen gave a result which approaches that required by theory.

0.1932 gr. of the salt dried *in vacuo* gave 0.0750 gr. of silver.

	Calculated for $AgC_{11}H_{13}O_2$.	Found.
Silver	37.89	38.82

The *barium salt* resembled the calcium salt in that it formed little balls of radiating needles, but showed a much greater tendency to separate in a viscous state, so that it was hard to obtain it crystallized.

The behavior of the *zinc salt* is very characteristic; when a solution of it is prepared by boiling the acid with water and zincic oxide, allowing the liquid to cool, and filtering, the clear solution thus obtained becomes turbid, when warmed even to temperatures far below the boiling-point, but clears up again as the liquid cools. The salt could be obtained only as a viscous mass.

B. *Study of the Residue from Distillation with Steam.*

The flask-residue, after the turmeric acid had been distilled off with steam, contained a black tarry substance, and not infrequently a white crystalline acid, which can be separated from the tar by treatment with boiling water. On extracting with ether the aqueous mother-liquor, from which the white acid had crystallized, a third substance, yellow and buttery, was obtained. All these substances are acids,

but we have been unable to bring the black tarry acid or the yellow buttery one into a state fit for analysis, and can only say that the very ill-defined calcium salt of the former contained 1.69 per cent of calcium, while the latter gave on oxidation an acid melting near 180°, which was not phthalic acid, and was formed in such small quantity that we were unable to determine whether it was a pure substance or only a mixture of apoturmeric acid with some impurity.

Apoturmeric Acid. The white crystalline acid was separated from its impurities by crystallization from boiling water, till it showed a constant melting-point. The same acid is obtained by oxidizing calcic turmerate with a hot solution of potassic permanganate, and a good part of the substance used for analysis was prepared in this way; the yield, however, was so small, not over 10 per cent of the turmeric acid used, that we have been unable to determine even its formula with certainty, as will be seen from the following analyses.

0.1138 gr. of substance gave 0.2582 gr. of carbonic dioxide and 0.0590 gr. of water.

	Calculated for $C_{10}H_{10}O_4$.	Found.	Calculated for $C_{10}H_{12}O_4$.
Carbon	61.86	61.87	61.22
Hydrogen	5.15	5.76	6.12

The *calcium salt* made by boiling the acid with calcic carbonate and water gave the following results: —

I. 0.2274 gr. of salt dried *in vacuo* lost 0.0304 gr. when heated to 100°.

II. 0.1390 gr. lost 0.0186 gr. when heated to 100°.

	Calculated for $CaC_{10}H_8O_4 2H_2O$.	Found. I.	Found. II.	Calculated for $CaC_{10}H_{10}O_4 2H_2O$.
Water	13.43	13.36	13.39	13.33

0.1826 gr. gave 0.3370 gr. of carbonic dioxide, 0.0758 gr. of water, and 0.1016 gr. of calcic sulphate.

	Calculated for $CaC_{10}H_8O_4$.	Found.	Calculated for $CaC_{10}H_{10}O_4$.
Carbon	51.72	50.32	51.29
Hydrogen	3.40	4.61	4.27
Calcium	17.24	16.36	17.10

The *barium salt* prepared like the calcium salt gave a result which is not in harmony with the preceding.

0.2704 gr. of salt dried at 100° gave 0.1742 gr. of baric sulphate.

	Calculated for $BaC_{10}H_8O_4$.	Found.	Calculated for $BaC_{10}H_{10}O_4$.
Barium	41.64	37.87	41.39

If, however, we suppose that the salt retained two molecules of water at 100°, the result agrees very well with the calculated per cents.

	Calculated for $BaC_{10}H_8O_42H_2O$.	Found.	Calculated for $BaC_{10}H_{10}O_42H_2O$.
Barium	37.53	37.87	37.32

But this supposition is, to say the least, improbable, as the calcium salt loses its water easily at 100°; unfortunately, we did not have enough of the acid to repeat the analysis of the barium salt.

Properties. The apoturmeric acid separates from its solution in boiling water as a white, rather stiff, wooly mass, which renders the whole solid, if the solution was a strong one; it melts at 221°, and is easily soluble in alcohol, ether, and boiling water; nearly insoluble in cold water.

Ammonic apoturmerate is not very freely soluble, and gives the following characteristic precipitates: With plumbic acetate, white flocculent; with cupric sulphate, whitish green, — both soluble in an excess of the precipitant; with mercurous nitrate, white flocks; with ferric chloride, yellowish white; with argentic nitrate, a heavy white precipitate, slightly soluble in boiling water. With the other common reagents it gives no precipitates at all, or very slight white ones.

Several attempts were made to oxidize the apoturmeric acid, but they gave no satisfactory result. The acid was attacked only with difficulty either by potassic permanganate or chromic anhydride, and the only insoluble substance left after the oxidation was simply undecomposed apoturmeric acid. In no case have we observed the formation of terephthalic acid from apoturmeric, or from carefully purified turmeric acid; but this acid has appeared when a calcic turmerate containing the non-crystalline impurity was oxidized. We should therefore ascribe the formation of terephthalic acid from turmerol by violent oxidation rather to this substance than to the turmeric acid formed; but our experiments must be repeated on a larger scale before we can consider this point finally settled.

It is to be regretted that we were unable to settle definitely the composition of the apoturmeric acid, as this would have thrown much light on the constitution of turmeric acid; as it is, it is not worth while to advance any hypotheses on this subject.

We may add one more observation in reference to turmerol, viz. isobutylturmerol does not give an addition-product with bromine, but there is formed with evolution of hydrobromic acid a most uninviting unstable viscous oil.

VII.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON THE ACTION OF PHOSPHOROUS TRICHLORIDE ON ANILINE.

By C. Loring Jackson and A. E. Menke.

Presented May 29, 1883.

The only paper on this subject which we have been able to find was published by Tait in 1865;* in it he describes the product of the action of phosphorous trichloride on aniline as a white salve-like mass easily soluble in water, alcohol, and ether, which, when freed from an excess of aniline, had the composition $(C_6H_5NH)_3P3HCl$, gave a chlorplatinate and several double salts, but yielded no satisfactory result when he attempted to set free the base.

We were induced to take up the study of this reaction by the hope that a further investigation of Tait's substance might lead to interesting results; but in this we were disappointed, as we have not succeeded in obtaining it, and, as far as our experiments go, are inclined to think it must have been a mixture instead of a definite compound. At the same time, we cannot state with absolute certainty that it is not present in the product formed when a decided excess of aniline is used, since the impossibility of continuing our work after the beginning of the summer vacation prevented us from making the investigation of this product as thorough as we wished. For the same reason other parts of this research can be published only in a very fragmentary and imperfect condition.

The isolation of the compounds containing phosphorus formed by the action of phosphorous trichloride on aniline, in the proportion of one molecule to three, is surrounded by difficulties which we have found insurmountable; but, in spite of this, our experiments have determined with a fair degree of certainty the nature of these compounds, as will appear from the following general statement of our results, and the argument which can be based upon them.

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* Jahresbericht der Chem. 1865, p. 411. Instit. 1865, p. 254.

When aniline is added to phosphorous trichloride in the proportion of three molecules of the former to one of the latter, the product, a variable mixture of aniline chloride and a substance containing phosphorus, gives a clear solution with water or alcohol. If, however, this product is heated, a waxy mass is obtained, which is soluble in alcohol; but water throws down from this solution a white precipitate having the formula $(C_6H_5NH)_2PHO$. Of the three most probable products of the reaction of phosphorous trichloride and aniline,

(1) $C_6H_5NHPCl_2$,
(2) $(C_6H_5NH)_2PCl$,
(3) $(C_6H_5NH)_3P$,

only (2) could yield $(C_6H_5NH)_2PHO$ by the action of water or alcohol, and we therefore infer that $(C_6H_5NH)_2PCl$ exists in the product after it has been heated. On the other hand, this substance cannot exist in the original product, as this dissolves in water without residue, whereas $(C_6H_5NH)_2PCl$ is converted by water into the insoluble $(C_6H_5NH)_2PHO$; but it must be formed from one of the constituents of the crude substance during the heating. Of the two probable products of the reaction, (1) and (3), mentioned above, it is hard to see how (3), $(C_6H_5NH)_3P$, by heating with aniline chloride, could be converted into $(C_6H_5NH)_2PCl$, while (1), $C_6H_5NHPCl_2$, could easily undergo this change under these conditions; from which we conclude that $C_6H_5NHPCl_2$ and aniline chloride are the products of the action of aniline on phosphorous trichloride under the conditions mentioned. This conclusion is supported by the fact that alcohol or water acts violently on the original product forming aniline phosphite, and it is highly improbable that $(C_6H_5NH)_3P$ would give such a violent reaction.

The remainder of this paper contains a detailed account of the experiments on which the above conclusions are based, a description of the properties and behavior of the new substance $(C_6H_5NH)_2PHO$, and a somewhat fragmentary account of two crystalline substances formed by boiling the crude product with an excess of aniline, one of which may be a derivative of $(C_6H_5NH)_3P$, although this point needs confirmation by further experiments.

Action of Phosphorous Trichloride on Aniline.

When aniline is added to phosphorous trichloride, the reaction is attended with so much heat, that each drop of the aniline hisses like

red-hot iron in water when it touches the trichloride; and, if the substances are mixed in about the proportion of three molecules of aniline to one of the trichloride, the product is a hard white solid, with no trace of the salve-like consistency described by Tait. It was proved to be a mixture by the following analyses of three different preparations, which were freed from an excess of either reagent by washing with ether before analysis.

	I.	II.	III.
Carbon	50.82	54.41	43.59
Hydrogen	6.28	7.07	7.10
Chlorine	19.38	23.15	
Phosphorus	5.48	2.92	

In the hope of isolating the phosphorus compound, the action of various solvents on the mass was studied, — of all the common solvents, water, alcohol, methyl alcohol, and acetone were the only ones in which it was not essentially insoluble; but, as we found that acetone dissolves aniline chloride, there was no prospect of achieving the purification of the phosphorus compound by its means, and either water or alcohol decomposed it, giving a clear solution,* which, on evaporation, left a viscous residue, apparently composed of chloride and phosphite of aniline, as it deposited crystals of the former after standing for some time, and upon solution in water and addition of plumbic acetate gave a heavy white precipitate, which, freed from plumbic chloride by washing with hot water, was proved to be plumbic phosphite, by the following analysis: —

0.6986 gr. of the salt gave 0.7380 gr. of plumbic sulphate.

	Calculated for $PbHPO_3$.	Found.
Lead	72.13	72.16

From this result it is probable that no anilidophosphorous acid was formed.

From what has been said, it appears that the product described above differs from Tait's in consistency, in its solubility in ether, and in composition; but if, instead of fulfilling the conditions given above, the trichloride is added to a large excess of aniline, a substance is obtained which resembles Tait's in its salve-like consistency and the fact that it gives a considerable extract with ether; at the same time, we cannot think that it has the composition ascribed to it by him,

* When water was used, there was sometimes a slight residue of $(C_6H_5NH)_2PHO$.

because our analyses given above show that the substance must contain aniline chloride, and this would not have been removed by mere solution in water, the only purification to which it was submitted by Tait. We may add, that the solid matter apparently extracted by ether was really dissolved in the excess of aniline, as it proved insoluble in ether after the aniline was removed, and, as aniline dissolves aniline chloride, we saw no prospect of purifying the phosphorus compound in this way. If, on the other hand, an excess of phosphorous trichloride was used, the product was a white compact mass, from which a considerable amount of solid matter was extracted with ether; but this was due evidently to its solubility in phosphorous trichloride rather than in ether, and, as it contained only two per cent of phosphorus, it was not thought worth while to pursue this part of the subject further.

Action of Heat on the Original Product.

If the mixture, analyses of which were given above, is heated, it turns orange-red, and gives off aniline chloride, the purity of which was determined by analysis, and a small quantity of a phosphorescent gas, probably phosphoretted hydrogen. This change takes place slowly and partially even at 100°, much more rapidly and completely at 150°, or at even higher temperatures. We usually heated the mass in a porcelain dish over a free flame, regulating the temperature so that aniline chloride sublimed off freely, but no spontaneously inflammable phosphoretted hydrogen was given off. The product when heated with alcohol gave a colorless solution, and a residue of an orange or red color, according to the length of time it had been heated. As this residue was insoluble in all solvents, and could not be purified completely by washing, we are in doubt as to its precise nature; but, as one preparation contained as much as 81.73 per cent of phosphorus, it cannot be an organic compound, but is either amorphous phosphorus, or the red oxide or solid hydride of that element. The alcoholic solution when treated with water gave a white precipitate of $(C_6H_5NH)_2PHO$, while aniline chloride and phosphite were left in solution with, so far as we could find, no other substances. The formation of the red body is not essential to the production of the mother-substance of $(C_6H_5NH)_2PHO$, as we obtained, by short heating in a dry test-tube, a yellowish waxy mass, which dissolved completely in alcohol and yielded a large amount of $(C_6H_5NH)_2PHO$ on addition of water; upon longer heating, however, the yellowish substance turned orange-red.

Before going to the description of the phosphorous anilid $(C_6H_5NH)_2PHO$, we may add, that we tried to obtain the chlorine compound from which it is formed by treating the freshly heated orange mass with benzol or with absolute ether, as these solvents seemed to offer the best chance of success. The amount extracted in either case was extremely small, and possessed the most unpromising properties, the ether extract containing lumps of ordinary phosphorus imbedded in a viscous mass, while the benzol extract resembled semiliquid paint, and gave no evidence that it was a homogeneous compound; it was analyzed, however, and contained 5.12 per cent of chlorine and 21.27 per cent of phosphorus, whereas $(C_6H_5NH)_2PCl$ requires 14.17 per cent of chloride and 12.37 of phosphorus.

Phosphorous Anilid $(C_6H_5NH)_2PHO$.

The preparation of this substance has been just described. In order to purify it, as it did not crystallize, the crude precipitate was redissolved in a little alcohol, and precipitated with water; the viscous mass thus obtained was kneaded thoroughly with water, dissolved again in alcohol, and once more precipitated and washed with water; it was then dried at about 50°, and its composition determined by the following analyses of a number of different preparations: —

I. 0.3488 gr. of substance gave 0.7992 gr. of carbonic dioxide and 0.1918 gr. of water.

II. 0.2856 gr. gave 0.6502 gr. of carbonic dioxide and 0.1610 gr. of water.

III. 0.2190 gr. gave 0.5012 gr. of carbonic dioxide and 0.1180 gr. of water.*

IV. 0.3402 gr. gave after treatment, according to Carius, 0.1590 gr. of magnesic pyrophosphate.

V. 0.2016 gr. gave 0.0976 gr. of magnesic pyrophosphate.

VI. 0.4623 gr. gave 49.9 c.c. of nitrogen at a temperature of 25° and pressure of 766 m.m.

	Calculated for	Found.					
	$(C_6H_5NH)_2PHO$.	I.	II.	III.	IV.	V.	VI.
Carbon	62.07	62.47	62.04	62.41	—	—	—
Hydrogen	5.60	6.10	6.26	5.99	—	—	—
Phosphorus	13.36	—	—	—	13.05	13.52	—
Nitrogen	12.07	—	—	—	—	—	12.13

* We found it best to carry on the combustions in a closed tube, the substance being mixed with oxide of copper, as if burnt in a boat in oxygen the carbon was apt to come low, since the fused phosphoric acid prevented the complete combustion of the substance.

Properties. It forms a white amorphous mass which melts at 87°; all our attempts to obtain it in crystals have been unsuccessful; it is freely soluble in cold alcohol and in ether, insoluble in cold water, but melts under boiling water, and perhaps dissolves to a very slight extent. It is a perfectly neutral body, neither acids nor alkalies affecting it in the cold; even alcoholic sodic hydrate or sodic ethylate acts on it with difficulty; on the other hand, fuming hydrochloric acid, when boiled with it for twelve hours, decomposes it completely into aniline chloride, phosphoric acid, and a small quantity of carbonaceous substance. The formation of the aniline chloride was proved by an analysis of the sublimate, 0.2776 gr. giving 0.3114 gr. of argentic chloride,

	Calculated for $C_6H_5NH_3Cl$.	Found.
Chlorine	27.41	27.74

the formation of phosphoric acid by qualitative tests with argentic nitrate and ammonic molybdate.

Action of Nitric Acid. When the substance is gently heated with fuming nitric acid it forms a red solution, from which water precipitates a red resinous body which contains phosphorus, but was not studied further, as the quantity was not large, and its properties were uninviting. By far the principal products of the reaction were contained in the aqueous solution, which left on evaporation yellow crystals having acid properties, and easily characterized by their appearance and melting-point, 120°, as picric acid. Another preparation yielded instead of picric acid the unsymmetrical metadinitrophenol, melting at 113°–115°. These results can be explained by supposing that the nitric acid saponifies the anilid, forming aniline nitrate and phosphoric acid, and that the former is afterwards converted into the nitrophenols by the combined action of nitrous and nitric acids.

Action of Acetic Anhydride. If phosphorous anilid is heated with acetic anhydride and fused sodic acetate on the water-bath, and the product extracted with ether, a viscous mass is obtained, which gradually becomes partially converted into crystals free from phosphorus, melting at 112° after recrystallization from water, and therefore acetanilid.

From all the observations described above it appears that the substance behaves like an anilid of phosphorous acid.

Action of an Excess of Aniline on the Original Product.

If the immediate product of the action of phosphorous trichloride and aniline, or this product after it has been heated, is boiled for some time with an excess of aniline, there results a mixture of various substances from which we have succeeded in isolating the orange-red substance and phosphorous anilid already described, chloride and phosphite of aniline, and a crystalline substance melting at 208°. There seems to be also a substance with a higher melting-point, and on one occasion a body melting at 150° was obtained; unfortunately we were obliged to break off work on this part of the subject before we had done more than analyze the two substances melting at 208° and 150° respectively, so that we have as yet no satisfactory data for determining their constitution, and also have been able to make no exhaustive search for other products.

Substance melting at 208°. This compound is obtained from the mixed products of the reaction by washing out the soluble salts with water, extracting the residue with hot alcohol, and purifying the extract by crystallization from alcohol, till it shows a constant melting-point. It was dried at 100° and analyzed.

I. 0.3352 gr. gave 0.8032 gr. of carbonic dioxide and 0.1770 gr. of water.

II. 0.2946 gr. gave 0.7047 gr. of carbonic dioxide and 0.1520 gr. of water.

III. 0.2528 gr. gave 0.1200 gr. of magnesic pyrophosphate.

IV. 0.2492 gr. gave 0.1200 gr. of magnesic pyrophosphate.

V. 0.3424 gr. gave 40.44 c.c. of nitrogen at a temperature of 20°.5 and a pressure of 757.3 m m.

	I.	II.	III.	IV.	V.	Mean.
Carbon	65.34	65.24	—	—	—	65.29
Hydrogen	5.86	5.73	—	—	—	5.79
Phosphorus	—	—	13.25	13.47	—	13.36
Nitrogen	—	—	—	—	13.38	13.38

These results agree most nearly with the formula $(C_6H_5NH)_8P_4OH_2$, but are not far removed from $(C_6H\ NH)_7P_3O_2H_2$, as is shown by the following comparison: —

	Calculated for $(C_6H_6N)_8P_4OH_2$	Mean of analytical results.	Calculated for $(C_6H_6N)_7P_3O_2H_2$.
Carbon	65.61	65.29	65.37
Hydrogen	5.71	5.79	5.70
Phosphorus	14 12	13.36	12.06
Nitrogen	12.75	13.38	12.71

According to the first of these formulas the substance would be a derivative of the red oxide or hydrate of phosphorus, while the second can be developed into $[(C_6H_5NH)_3P]_3H_2O_2PC_6H_5NH$; it is possible, therefore, that a study of the decomposition-products of the substance might throw light on its composition. With this view we heated some of it to 140° in a sealed tube with hydrochloric acid, and obtained phosphorous and phosphoric acids, aniline chloride, some carbon, and an odor of phenol, but no red product; we have also found that boiling aniline with the red substance, so often mentioned, does not give this compound melting at 208°, so that our results are in favor of the second formula so far as they go, but need revision before much weight can be given to them.

Properties. The substance crystallizes in small white prisms apparently of the monoclinic system, or in long radiating needles with, as far as we could determine, the same melting-point and composition as the prisms; it melts at 208°, and is insoluble in water, freely soluble in hot alcohol, less so in cold, essentially insoluble in ether. Potassic hydrate in aqueous solution does not act on it at first, but gradually decomposes it if the two are boiled together; sulphuric acid acts in the same way; the decomposition with hydrochloric acid has been described already.

Substance Melting at 150°. This compound was obtained at the very end of the term in an attempt to prepare more of the substance melting at 208°; on this account we cannot give the conditions which determine its formation, or anything more concerning it than the following analyses: —

0.3492 gr. of substance gave 0.7122 gr. of carbonic dioxide and 0.2004 gr. of water.

0.2562 gr. gave, according to Carius, 0.1330 gr. of argentic chloride and 0.0890 gr. of magnesic pyrophosphate.

	Found.
Carbon	55.62
Hydrogen	6.37
Chlorine	12.83
Phosphorus	9.70

It would not be worth while to attempt to determine the formula of this substance until these results have been tested by further analyses. It crystallizes in rather thick white radiating needles, melts at 150°, and resembles the preceding substance in a general way in its solubility.

At no distant date we hope to be able to return to the study of

this subject in order to determine the nature of the two substances just described, to investigate more thoroughly the products of the reaction, which are soluble in water, and to take up the compounds formed by aniline and phosphorous trichloride in presence of diluents, which, according to a preliminary experiment, promise to be of great interest.

VIII.

RESEARCHES UPON THE PHOTOGRAPHY OF PLANETARY AND STELLAR SPECTRA.

By the late Henry Draper, M. D., LL. D.

With an Introduction by Professor C. A. Young, *a List of the Photographic Plates in Mrs. Draper's Possession, and the Results of the Measurement of these Plates by* Professor E. C. Pickering.

Presented April 11, 1883.

Introduction.

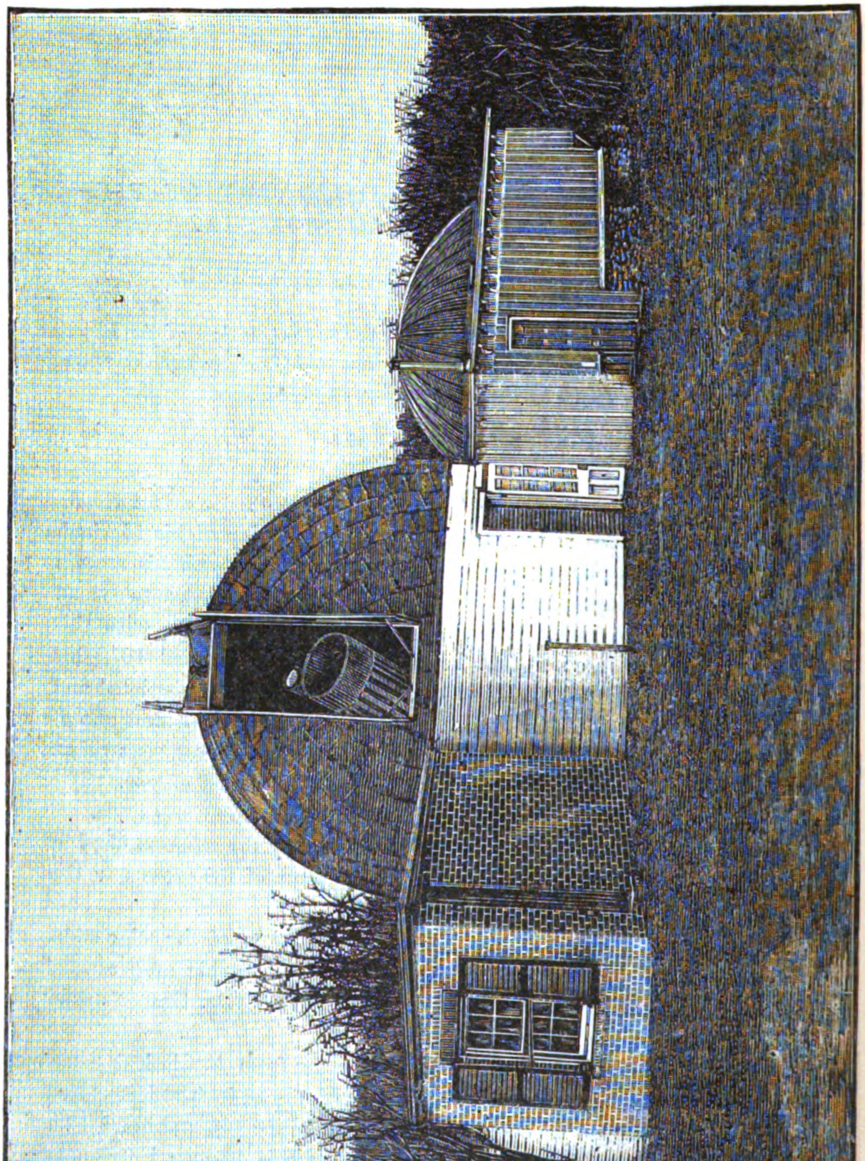
The early successes of Dr. Draper in the construction of his 15½-inch reflector, and his photography of the moon, together with his studies in spectrum photography in 1869 and 1870, led him to desire to extend his work to the investigation of stellar spectra. It was with this object specially in view that he constructed in 1869 and 1870 his great 28-inch silvered glass reflector, which was finally completed and ready for work in 1871, and in May, 1872, he obtained his first photographs of the spectrum of α Lyræ, by merely inserting a quartz prism in the path of the rays just inside the focus of the small mirror. The plates obtained on this occasion failed, however, to show any lines.

In August of the same year he succeeded by the same method in getting plates showing four lines in the spectrum of the same star, the least refrangible line being near G.

Other lines of work connected with investigations of the solar spectrum, and with the superintendence of the photographic preparations for the transit of Venus in 1874, occupied most of Dr. Draper's time for the next two or three years.

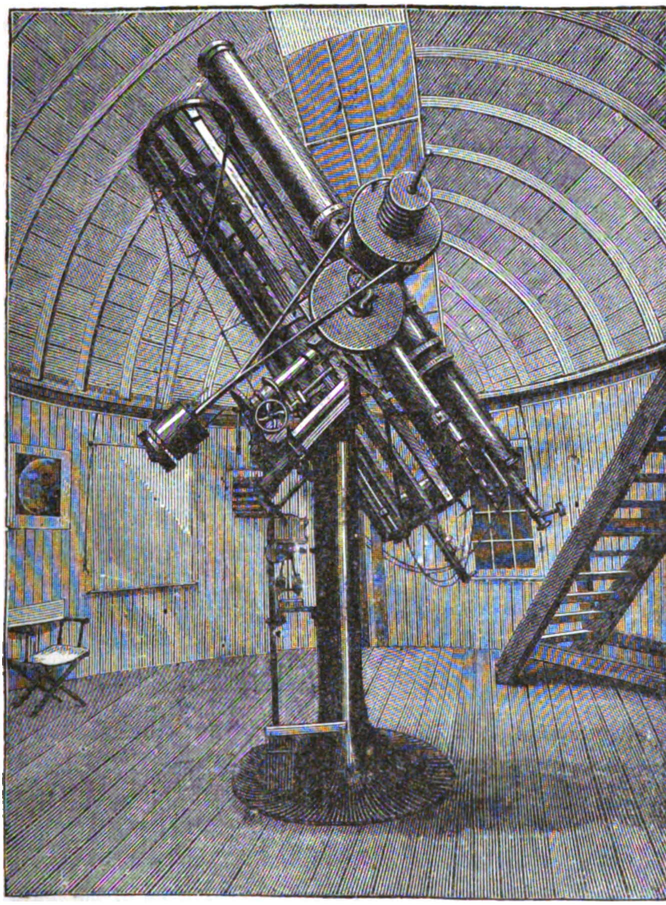
In 1875 he obtained a fine 12-inch refractor from A. Clark & Sons, which he mounted upon the same stand with his 28-inch reflector, and in 1876 he resumed his operations upon stellar spectra, and obtained a number of photographs, some of them with this 12-inch instrument and some with the 28-inch.

In the summer of 1880 he exchanged the 12-inch instrument for an 11-inch by the same makers, the new instrument having a special cor-



recting lens fitted to be placed in front of the object-glass to adapt it to photographic work.

At first, and until 1879, wet collodion plates were used in all these experiments; after that date, he used exclusively the dry plates of Wratten and Wainwright, to which, during a visit to England in 1879,



the attention of Dr. Draper was called by Dr. Huggins, whose admirable work in the same line of research is so well known to every one interested in such matters.

As will be easily understood, these operations upon stellar spectra were by no means carried on continuously, but only during Dr Draper's summer residence at his country place, and in the intervals of other,

to him, even more absorbingly interesting investigations, and urgent business occupations.

The observations were made in his private observatory at Hastings-on-the-Hudson, Lat. 40° 59′ 25″, Long. 73° 52′ 25″. Elevation above sea, 220 feet.

The pictures of the Observatory and of the Great Equatorial render unnecessary any detailed description of the mounting and general arrangement of the instruments.

The difficulties of the research proved to be very great. At first the limitations imposed upon the time of exposure by the use of the wet process made it almost impossible to get impressions of sufficient strength. This difficulty, however, is now a thing of the past, having vanished with the introduction of the modern dry-plate processes. Another difficulty, however, which increases with the time of exposure, is that of securing a sufficiently accurate movement of the driving-clock. Dr. Draper was obliged to construct no less than *seven* before he succeeded in getting one that was perfect. Other difficulties which were more or less completely overcome relate to the firm and rigid connection of the parts of the spectroscope with each other, and with the sensitive plate; to the effect of temperature upon this connection, and upon the dispersive power of the prisms employed; and to the method of obtaining a satisfactory reference spectrum for comparison with that of the star under examination. Of course, also, every one knows that operations of this kind are much more sensitive than visual observations to atmospheric conditions. A slight haze, which is rather an advantage than otherwise to ordinary work, cuts off the actinic rays to such an extent as to increase the needed time of exposure many fold. On some evenings, apparently good, it will take 30 minutes or an hour to obtain a picture as intense as could be obtained on others in 5 or 10 minutes.

Another serious practical difficulty should also be mentioned, — the fact that Dr. Draper's residence was distant more than two miles from his observatory; and this of course involved many absolute disadvantages and some loss of opportunities, as well as much inconvenience.

It is not necessary to give here any full description of the telescopes employed. It is enough to say that the great reflector constructed by Dr. Draper himself has a mirror of silvered glass 28 inches in aperture, with a focal length of 148 inches. It was generally fitted up in the Cassegrainian form, the small convex mirror, also of silvered glass, having a diameter of 8 inches and a negative focal length of 29 inches. It was placed 33 inches inside the principal focus of the great mirror.

Dr. Draper tried the effect of replacing the small convex mirror with a flat of 16 inches diameter for photographic work, but the result was not satisfactory.

In the use of the reflector for photographic and spectroscopic purposes it was found extremely difficult, in fact impossible, to hold the great mirror with sufficient firmness to keep the star image accurately in place, without at the same time distorting the glass and injuring the definition. In this respect the refractors had greatly the advantage, though of course they were much inferior in the amount of light.

The 12-inch refractor needs no special description. It had a focal length of 183 inches, and its color-correction was adjusted for the use of achromatic eyepieces, instead of the usual Huyghenian eyepieces. The correction, however, did not vary materially from that of other telescopes by the same makers, the difference of focal length between the mean rays of the spectrum and H amounting to about $\frac{8}{10}$ of an inch. It was an excellent instrument for all visual purposes, and is now owned by the Lick Observatory. For photographic purposes, however, it was decidedly inferior to the 11-inch instrument which succeeded it.

The focal length of the 11-inch telescope without its photographic corrector was about 176 inches; with the corrector applied, it was shortened by 24 inches.

With reference to the driving-clock it is only necessary to say that its regulator was a heavy conical pendulum, or rather pair of pendulums, weighing some 15 pounds, and so hung that their revolutions were sensibly isochronous through quite a range of inclination. Whenever by increase of driving power or decrease of resistance one of the balls rose above a certain limit, it acted, without affecting the radial motion of the ball, upon a friction spider which absorbed the superfluous energy in the manner made familiar by the chronographs constructed by the Clarks and by Fauth & Co., and now so common in our observatories. The regulator revolved once a second. The gearing and driving screw were constructed, for the most part, by Dr. Draper himself, with the utmost care and accuracy; and it may safely be said that in its ultimate perfected condition the driving-clock was as good as any in existence, keeping a star upon the slit for an hour at a time when near the meridian and not disturbed by changes of refraction.

In the course of the operations a great many forms of spectroscopic apparatus were employed. At first, as has been mentioned, a quartz prism was used, simply interposed in the path of the rays a few inches

inside the focus, without slit or lenses; and with this, after one or two unsuccessful trials, he first obtained a satisfactory spectrum of Vega showing four dark lines.

Afterwards direct vision prisms used in the same way were tried, and spectroscopes made up of such prisms, some with a slit, some without, and some with a cylindrical lens to give necessary width to the spectrum. The arrangement finally settled upon, however, and with which all the plates measured by Professor Pickering were made, was the following. A star-spectroscope by Browning, with two 60° prisms of dense (*but white*) flint glass, was used, of the form designed by Dr. Huggins for stellar observations. The telescope and collimator each had a focal length of 6 inches, with an aperture of $\frac{3}{4}$ of an inch. The parts were very carefully braced together to prevent any slip or movement. The slit was covered with a diaphragm having a hole at the centre, and painted with phosphorescent paint to make the aperture visible in the dark: there was also a movable "finger," by which any part of the slit could be exposed at pleasure, so as to obtain spectra of different objects on the same plate side by side for reference.

At the eye-end of the spectroscope-telescope the eyepiece and micrometer were removed, and a block of hard wood was fitted on in such a way as to carry the little photographic plate. This was a small bit, about an inch square, cut from a plate of commercial size. A small positive eyepiece was mounted on the block, so that the operator could at pleasure examine the yellow and red portion of the spectrum which projected beyond the sensitive plate into the field of view, and in this way assure himself that the clockwork was driving properly, and that all the adjustments remained correct.

The whole apparatus weighed less than five pounds, and screwed on to the eye end of whatever telescope it was used with.

On the most careful examination, it is very difficult to see how any perceptible alteration in the relative position of the different parts could ever have occurred. Still, the bracing employed was not absolutely symmetrical, and there may have been a little "twist" when the instrument was transferred from an object near the zenith on one side of the meridian to one near the horizon on the other.

For the most part the development of the plates was by ferrous oxalate, though the alkaline development and pyrogallic acid were both used on some occasions.

The pictures obtained with this arrangement were about one sixteenth of an inch in width and about half an inch long, extending from a point between the Fraunhofer lines F and G to a point near M.

Subjoined are certain notes which seem to be of interest, and important to a proper understanding of the manner in which the research was carried on and developed. They are condensed from the original note-book records.

"May 29, 1872. Two photographs of the spectrum of Vega were taken with collodion plates. The first was with an exposure of 3 minutes, the next of 30 seconds. No slit was used and no lenses. A quartz prism was placed inside of the focus of the telescope [the 28-inch Cassegrain], and a sensitive plate at the focus. The photographs showed no lines." It was then deemed better to reduce the magnifying power of the telescope, by using a flat mirror in place of the small convex. A flat mirror of 16 inches diameter was therefore ground and polished. When this was finished and put in place in the telescope, the three hooks by which it was supported caused it to deform the image of a star into a triangular form. Dr. Draper then tried supporting the flat by an iron plate cemented to its back, but with no better result. He then decided to try a 9-inch concave mirror of 11 inches focus, adapting to it a spectroscope formed by placing a slit at the focus, followed by a one-inch microscope objective, next a Hoffman direct-vision prism, succeeded by an eyepiece, and finally the sensitive plate. This apparatus gave too faint a spectrum, and he returned to the original arrangement, with which, on August 1, 1872, he obtained for the first time a photograph of the spectrum of Vega showing four lines. The width of the spectrum was obtained by giving the telescope a slight motion in declination, during the exposure. On August 8th and 9th he took several other photographs, the exposures ranging from 5 to 10 minutes. Of course with this arrangement no reference spectrum could be obtained.

Recurring to the subject in the summer of 1873, he took a spectrum of α Aquilæ, half an inch long and $\frac{1}{32}$ inch wide. It does not appear from the notes that it showed any lines: exposure 10 minutes.

During the same season Dr. Draper arranged a spectroscope consisting of a quartz prism combined with a cylindrical lens. It was abandoned because it gave the spectrum the form of an elongated image of the mirror, instead of a narrow band.

He next combined a heavy flint-glass prism of 60° with a quartz prism. This made nearly a direct vision spectroscope of good dispersive power, and with it he obtained the spectrum of α Aquilæ as a narrow band, in 5 minutes' exposure.

In 1874 Transit of Venus work occupied all his time. In October, 1875, several photographs of the spectrum of Vega were taken with

a Browning nine-prism direct-vision spectroscope (without slit) placed inside the focus of the 28-inch mirror, the sensitive plate being at the focus.

The 12-inch refractor was received at this time, and a good deal of photographic work was done with it to determine its actinic focus and other constants, but no photographs of stellar spectra were made with it this season. Its best actinic focus was found to be $\frac{62}{100}$ inch outside of the focus for G.

In July, 1876, several photographs of the spectrum of Vega were taken with an apparatus which Dr. Draper called the "spectrograph." It consisted of a box about three feet long, which screwed into the tailpiece of the reflector in place of the eyepiece. It consisted of the following parts: first, a slit; close behind this the brass tube of a Browning direct-vision spectroscope containing either 3, 6, or 9 prisms (variable at pleasure); next to this, and 14 inches from the slit, a 7-inch Voigtlander portrait-lens and camera. The results were not materially different from those obtained by the earlier methods, and the apparatus was so awkward that it was soon abandoned. At this time was introduced the plan of setting the slit in the direction of the right-ascensional motion, so that any slight irregularities of the driving-clock would only widen the spectrum a little, instead of removing the star's image from the slit. The use of a cylindrical lens to broaden the spectrum was not found to be of any particular advantage.

During September and early in October, 1876, experiments were tried by putting the Browning direct-vision prism, without slit or lens, inside the focus of the 12-inch refractor. A cylindrical lens of 14-inch focus could be placed either between the prism and the object-glass, or between the prism and the sensitive plate. The difficulty produced by the fact that the focus of the object-glass varies for different rays, was partly overcome by tilting the sensitive plate.

On October 9 the Huggins star-spectroscope seems first to have been brought into use, one prism only being employed. It was attached to the refractor, and at first used with wide open slit. It was found difficult but very important to adjust the collimator accurately in line with the optical axis of the large telescope.

On October 12 another stellar spectroscope was arranged, consisting, first, of a slit with an open space between it and the end of the telescope, so that one could see whether the star remained centred on the slit; then the nine-prism Browning direct-vision combination; then two opera-glass lenses, and behind this the plate-holder. This was attached to the reflector, and several stellar spectra were photographed

with it; but they turned out very faint, and the removal of the slit did not make them any brighter.

October 18 and 19, 1876. Experiments were made upon the spectrum of Venus, both with the reflector and refractor, — the former giving much the stronger pictures. The plates show the lines very well, especially those between G and H. At this time an eyepiece was added for the purpose of watching the lower end of the spectrum, and so maintaining the adjustments.

October 25, 1876. Six photographs of the spectrum of Venus were made, which came out very satisfactorily. Experiments were made, giving data for determining the best width of slit.

October 27, 1876. Some photographs of the spectrum of Vega were made with the same apparatus, but results were not very satisfactory. The air was misty.

October 29, 1876. In the afternoon the same stellar spectroscope was attached to the 12-inch refractor, the aperture of which was reduced to 1½ inches. The slit was closed so that *b* appeared distinctly triple, in the spectrum of the sun, and a series of photographs was made with exposures of 4 minutes, 1 minute, 5 seconds, and 1 second, respectively. The last proved just about the proper exposure, and indicates that the necessary exposure for Venus is 196 times that for the Sun.

During 1877 Dr. Draper was occupied mainly with work connected with his research upon the existence of oxygen in the Sun. In 1878 the season was occupied with the Transit of Mercury in May, and with the Solar Eclipse on July 29th; so that during these two years nothing was done with stellar spectra.

While in England, in June, 1879, he obtained some of Wratten and Wainwright's dry plates, and on his return resumed his stellar work with them. As the 28-inch mirror had not been resilvered since the removal of the film at the time of the Transit of Mercury, he used the 12-inch refractor for all his experiments, in connection with the Huggins star spectroscope, with *two* prisms, instead of only one, as in 1876. In October, he read before the National Academy of Sciences a paper upon the subject, which was published in the American Journal of Science for December, 1879.

The plates made by the collodion process up to and including 1876 were, of course, of no value for measurement, and have all been lost or destroyed, except about half a dozen "strippings" of the earliest ones, which still remain gummed into the note-books. For this reason it has seemed desirable to present the note-book data respecting them in the way which has been adopted.

In the list which follows, of the plates existing in the possession of Mrs. Draper, the remarks against each plate give all necessary details. The photographs were all taken with the Huggins star spectroscope with its two prisms, attached sometimes to the reflector, sometimes to the refractor, as indicated.

The first column of the table gives a current reference number; the second, the date; the third, the name of the object; the fourth, the local mean time of beginning of the exposure, when the note-books furnish it; the fifth, the duration of the exposure; the sixth, the width of the slit in thousandths of an inch; and the seventh, the aperture of the instrument used. Remarks follow quoted from the note-book. An asterisk denotes that the plate was one of those measured by Professor Pickering.

TABLE I.

No.	Date.	Object.	Time.	Expos.	Slit.	Inst.	Remarks.
	1879.						
1	Aug. 6	α Lyræ		45m.	.006	12-in	The spectrum is about ½ inch long from G to H. Put a finger in front of the slit so as to be able to shut off either the upper or lower part of it, and thus take a spectrum of a star with the moon or a planet juxtaposed upon the same plate for a reference spectrum.
2	Aug. 9	Sun		5s.			With the stellar spectroscope and a beam of sunlight from a heliostat, took some photographs of the sun's spectrum. Although the sun was somewhat obscured by clouds, 5 s. was too long an exposure, and the picture was burned out below H. The exposure of 30 s. to daylight answered better, and showed that these photographs extend nearly to F, instead of ending at G. On comparing these with the photograph of the spectrum of α Lyræ of August 6, it was found to extend above N (3580), and looks as if the great solar groups about L (3815) were represented in α Lyræ by bands.
3	Aug. 9	Daylight		30s.			
4	Aug. 11	Jupiter and α Lyræ		48m. 27m.	.007 .007	12-in. 12-in.	The evening was quite misty. — too much so to photograph the spectrum of α Bootis.
5	Aug. 12	α Lyræ and Jupiter	8h. 30m. to 12h.	40m. 30m.	.007 .007	12-in.	The evening was not clear, the sky being misty or covered by heavy clouds, which formed and dissolved away at intervals. The length of exposure specified is therefore uncertain, being the estimated clear periods during 3½ hours the plate was in the spectroscope. The mist cut off the more refrangible part of the spectrum. The two spectra shifted past each other a little in the photograph, but the adjacent coincidences are plain. To try to prevent, on another occasion, the spectra moving past each other when the telescope is changed from one star to another, as in the preceding photograph, the spectroscope was fastened to a piece of board.
6	Aug. 19	α Bootis		45m.		12-in.	Faint picture.

TABLE I. — *Continued.*

No.	Date.	Object.	Time.	Expos.	Slit.	Inst.	Remarks.
	1879.						
7	Aug. 19	α Lyræ and		47m.	.010	12-in.	Had to reverse the telescope for the exposure of α Lyræ, and, not having adjusted the finger well on the slit, the two spectra overlapped too much.
		Jupiter		47m.	.010	12 in.	
8	Sept. 15	Jupiter and		45m.	.011	12-in.	In this photograph the telescope was focused for the G rays on the slit.
		α Lyræ		43m.	.011	12-in	
9	Sept. 17	Jupiter		30m.	.015	12-in.	In this picture the H rays were focused on the slit, but as the spectra did not extend as far into the violet as those taken before, the focus of the 12-inch telescope was changed to bring the G rays in focus on the slit. Took another photograph. In this both spectra were stronger, but α Lyræ did not extend to H.
		α Lyræ		49m.	.015	12-in.	
10	Sept. 17	Jupiter		45m.	.015	12-in.	
		α Lyræ		45m.	.015	12-in.	
11	Sept. 22	α Lyræ		49m.	.015	12-in.	The atmosphere was misty, and the moon looked very yellow. The spectrum of α Lyræ is very faint, and extends only from F to G.
		Jupiter		50m.	.015	12-in.	
12	Sept. 24	α Lyræ		54m.	.015	12-in.	The night was quite clear, but neither spectrum extended above H. G was still focused on the slit.
		Jupiter		30m.	.015	12-in.	
13	Sept. 24	Mars	11h. 30m. to	55m.	.015	12-in.	Mars and α Aurigæ were at about the same altitude. The two spectra are very much alike.
		α Aurigæ	13h. 15m.	48m.	.015	12-in.	
14	Sept. 25	α Lyræ		103m.	.015	12-in.	The night was clear. Gave α Lyræ two runs of the clock to try to get its spectrum above H. The moon's spectrum extends a long distance above H, but the spectrum of α Lyræ only to *h*. The moon was over-exposed.
		Moon		30m.	.015	12-in.	
15	Sept. 26	α Lyræ		45m.	.015	12-in.	The night was quite clear. The moon's spectrum is very strong, but there is no picture of α Lyræ. In this photograph, used a new gelatine plate, thinking the old one might have deteriorated, but found it of no advantage. When a star is adjusted on the slit so that the green end of the spectrum is the brightest, the violet loses brightness somewhat, and *vice versa*. Examined the spectroscope with sunlight and readjusted it, so as to be sure the violet end of the spectrum was not cut off by the prisms or lenses.
		Moon		10m.	.015	12-in.	
16	Sept. 27	α Lyræ		47m.	.015	12-in.	This evening went to the Observatory early enough to photograph the spectrum of α Lyræ, when the star was only a little past the meridian. Readjusting the spectroscope improved it. The spectra are strong, and extend above H. The G rays were focused on the slit.
		Moon		5m.	.015	12-in.	
17	Sept. 27	Jupiter	9h. 55m. to	50m.	.005	12-in.	Jupiter in this photograph was about 45° high, and the Moon about 50°. The exposure was made upon the meridian. During the latter part of the moon's exposure. the lens dewed over, therefore one could not judge of the relative brightness of the two. H rays were focused on the slit.
		Moon	10h. 55m.	10m.	.005	12 in.	
18	Sept. 27	Moon	11h. 21m. to	10m.	.005	12-in.	Got no impression of Mars, for the lens dewed over at the end of 25 m., and the sky clouded.
		Mars	12h.	25m.	.005	12-in.	
19	Oct. 4	α Lyræ	8h. 5m. to	45m.	.010	12-in	A good picture.
		Jupiter	9h. 20m.	25m.	.010	12-in	
20	Oct. 4	Jupiter	10h. 25m.	25m.	.010	12 in.	H rays focused on the slit. Spectrum of α Aurigæ was faint.
		α Aurigæ	11h. 48m.	50m.	.010	12-in.	

TABLE I. — *Continued.*

No.	Date.	Object.	Time.	Expos.	Slit.	Inst.	Remarks.
	1879–80.						
*21	Oct. 4	α Aurigæ	12h. to	54m.	.010	12-in.	G rays focused on the slit.
		Moon	13h.	5m.	.010	12-in.	A good picture. During the winter of '79 and '80 a new worm wheel was made by Alvan Clark & Sons for the driving-clock, to replace the old one, which was found to be slightly eccentric. Dr. Draper moved to the country in June, 1880, and occupied a few days in getting it into place. It answered extremely well, and the clock was now sensibly perfect.
	1880.						
22	June 9	α Bootis	9h. 27m. to 10h. 16m.	49m.	.010	12-in.	G rays were focused on the slit The night was clear, but the picture is faint.
*23	June 13	α Bootis	9h. 20m. to 9h. 50m.	30m.	.015	12-in.	At the end of 30 m. the exposure was stopped by clouds. The night was so windy that the dome was blown around, and the force of the wind overcame the strength of the declination clamp, so that the telescope moved in declination, and made two impressions of the spectrum on the plate. Notwithstanding this, it is a good picture, extending from above H_2 to below F, showing a large number of lines, and a bright band on the more refrangible side of H. The G rays were focused on the slit.
*24	June 16	α Bootis	8h. 35m. to	50m.	.015	12-in.	Moon over-exposed, and α Bootis faint.
		Moon	9h. 30m.	3m.	.015	12-in.	The night was damp and not clear; bluish fog. At this time Dr. Draper exchanged the 12-inch for the 11-inch with photographic corrector referred to above. The new instrument was received July 9th, but was not fully ready for work until near the end of the month. The 28-inch reflector had been resilvered in the mean time, so that the spectroscope could be used either with it or with the refractor.
25	July 28	α Scorpii				11-in.	Sky clouded so there was no impression on the plate.
*26	July 29	α Lyræ	9h. to 9h. 25m.	25m.	.010	28-in.	Only about fifteen minutes of this exposure were clear, but it is a strong picture. The clouds cleared away, and the night became remarkably clear.
27	July 29	α Aquilæ		43m.	.010	28-in.	Fine picture.
28	July 29	α Aquilæ		33¼m. 4¾m.	.010 .010	11-in. 11-in.	At the end of 33¼ m., the star having moved to the west of the meridian, a slip in declination took place, owing to taking up the slack. This changed the position of the star on the plate, and made a second impression of 4¾ m.
29	July 30	α Scorpii	8h. 51m. to	45¾m	.010	11-in.	Atmosphere was hazy, and the first 16 m. of the exposure α Scorpii was very
		α Aquilæ	10h. 10m.	30m.	.010	11-in.	faint on account of clouds It had a good exposure of 30 m. After 9 o'clock the night was clear. α Scorpii's spectrum was faint, α Aquilæ's very strong.
*30	July 30	α Lyræ		7m. 28¾m.	.010 .010	11-in.	Before making this exposure on α Lyræ, moved the slit of the spectroscope outside the focus of the telescope 448 divisions of the micrometer, so as to widen the spectrum. After an exposure of 7 m. shifted the star on the plate, and then gave it the remaining time, 28¾ m., but the two pictures are nearly superposed.

TABLE I. — *Continued.*

No.	Date.	Object.	Time.	Expos.	Slit.	Inst.	Remarks.
	1880.						
31	July 30	α Lyræ		4m. 30m.	.010 .010	11-in. 11-in.	Before this exposure, moved the slit of the spectroscope 394 divisions more outside the focus. The star was shifted on the plate after 4 m , making the second exposure of 30 m.
*32	July 31	α Bootis	8h. 49m. to 9h. 19m.	4½m. 25m.	.010	28-in.	The telescope slipped at the end of 4½ minutes, making two exposures on the plate. It was remarkably clear for a summer's night.
33	July 31	α Aquilæ		30m. 10m. 5m.	.010	28-in.	There are three exposures, the plate having been moved sideways at the end of 30 m., then again after 10 m., giving it a third exposure of 5 m. This picture required short development.
*34	July 31	α Lyræ		6m. 20m. 5m.	.010 .010 .010	28-in.	For this photograph, moved the spectroscope slit outside the focus to widen the spectrum. Made three exposures on the plate. The wind was so strong it moved the telescope in declination, and made it difficult to keep the star on the slit. This picture required short development.
*35	July 31	Jupiter		20m. 30m.	.010 .005	28-in.	At the end of 20 m. closed the slit to .005, and moved the star on the plate for the second exposure.
36	Aug. 1	α Scorpii		20m. 17m.	.010	28-in.	At the end of 20 m. the star slipped off the plate. Reset it, and exposed again for 17 m. During the first exposure the star was part of the time very faint In the spectrum of α Scorpii there is a strong band in the orange.
37	Aug. 6	Jupiter	14h. 35m. 15h. 5m.	30m.	.006	11-in.	In the early part of the night took several photographs of Jupiter, showing the red spot. In taking this picture of the spectrum, placed the slit of the spectroscope near the preceding limb where the red spot was seen, but it had nearly disappeared.
38	Aug. 7	α Aquilæ		30m.	.006	11 in.	
*39	Aug. 9	α Scorpii	8h. 46m. to 9h. 26½m.	45½m.	.020	28-in.	Faint picture.
40	Aug. 9	α Aquilæ		10m. 15m. 12½m.	.020 020 .020	28-in.	Star moved off the slit, and was reset between the exposures. The atmosphere was hazy.
*41	Aug. 12	α Aquilæ	9h. 47m. to 11h.	24m. 5m. 44m.	.010 .010 .005	28-in.	Night quite clear. At end of 24 m. star moved off the slit; reset it, and exposed again for 5 m. Moved the star again, closed the slit to .005, and made third exposure of 44 m.
*42	Aug. 12	α Aquilæ α Aquilæ Jupiter		18m. 10m. 12m.	.010 .010 .010	28-in. 28-in. 28-in.	α Aquilæ moved off the slit at 18 m , and was reset. 12 m. was not enough exposure for Jupiter; 15 or 20 would have been better.
*43	Aug. 12	α Aurigæ Jupiter	13h. 55m. to 14h. 47m.	30m. 20m.	.010 .010	28-in.	The image of the star was not quite focused on the slit.
44	Aug. 13	α Aquilæ		30m.	.010	28-in.	There was white mist in the sky.
	Aug. 13	α Lyræ		10m. 10m. 10m.	.003	28-in.	Reset the star between each of the three exposures.
*45	Aug. 15	α Lyræ		46m.	.002	28-in.	α Lyræ was not focused on the slit.
*46	Aug. 15	α Lyræ		44m.	.001	28-in.	Focused α Lyræ on the slit.
47	Aug. 16	α Scorpii Moon		42m. 8m.	.010 .010	28-in.	There was blue haze in the atmosphere. The finger on the slit was moved between the exposures of α Scorpii and the Moon, but was not well adjusted, so the two spectra are superposed.

TABLE I. — *Continued.*

No.	Date.	Object.	Time.	Expos.	Slit.	Inst.	Remarks.
	1880-81.						
*48	Aug. 17	α Scorpii	8h. 12m. to 9h. 2m.	50m.	.010	28-in.	There was blue fog in the sky.
49	Aug. 17	α Aquilæ		49m.	.003	28-in.	The star slipped in declination at the end of 20 m., and again at 30 m., but was brought in position in a couple of minutes by the slow motion. The evening continued foggy.
50	Aug. 20	α Aquilæ		48m.	.001	28-in.	The plate was stained black by the moon-light in the room.
51	Aug. 22	α Aquilæ		48m.	.001	28-in.	The sky was hazy, but the picture is beautifully sharp, and shows the fine lines of this spectrum very distinctly.
52	Aug. 22	α Aquilæ Moon		49m. 5m.	.001 .001	28-in.	The moon's spectrum is faint, and α Aquilæ is not quite so sharp as in the preceding photograph.
53	Aug. 22	α Lyræ		48m.	.001	28-in.	This photograph was taken without any change being made in the apparatus, to see if, in the spectrum of α Lyræ, there was any trace of the system of fine lines which are characteristic of the spectrum of α Aquilæ, but no evidence of them was found. With the McLean spectroscopic eye-piece α Lyræ shows a line near D which may be D_3.
54	Aug. 23	α Bootis	8h. 12m. to 9h. 2m.	50m.	.001	28-in.	The spectrum is very faint. The evening was misty.
55	Aug. 23	α Aurigæ		48m.	.001	28-in.	Although the evening was clear, the spectrum is faint.
*56	Aug. 28	α Aquilæ Jupiter	10h. 20m. to 12h. 9m.	49m. 50m.	.002 .002	28-in.	A very good picture; the night was quite clear.
*57	Aug. 28	Jupiter α Aurigæ	12h. 45m. to 14h. 18m.	35m. 48m.	.003 .003	28-in.	The spectrum of α Aurigæ is quite faint. To get a strong picture, it would require the slit at .004 or .005, or else two runs of the clock.
	1881.						
58	July 1	Comet *b* α Lyræ	10h. 55m 14h. 10m.	180m. 10m.		11-in	The comet's declination at 10h. 45m. was 70°. The slit of the spectroscope was set at right angles to the axis of the tail of the comet. The spectroscope showed a banded spectrum, with the continuous spectrum of the nucleus running through the centre. The photograph shows three bands, a heavy band above H which is divisible into lines, and two faint bands, one between G and *h*, and another between *h* and H.
59	July 2	Moon		8m.	.006	11-in.	There was mist in the sky, which with
60	July 2	Moon		10m	.013	11 in.	the low altitude of the moon cut off these spectra above H.
61	July 2	Comet α Lyræ	10h. 8m. to 13h. 23m.	136m. 15m.	.016 .016	11-in. 11-in.	There were floating clouds in the sky, and for about 42 m. of its exposure the comet was not visible. At 11h. 20m. the comet's declination was 72½°.
62	July 3	Comet α Lyræ	10h. 55m. to 14h.	228m. 10m.	.016 .011	11-in. 11-in.	Stopped the exposures always before dawn, fearing otherwise that the spectrum of daylight might become superposed on the cometary spectrum. July 7th, took the stellar spectroscope to the laboratory in town, and made a series of carbon arc spectra, with the sun's spectrum on the same plate as a reference spectrum, for comparison with the comet's spectrum. The carbon shows a strong band in the ultra violet.
*63	July 15	α Lyræ Moon	11h. 30m. to 12h. 20m.	34m. 15m.	.002	11-in.	Night became foggy, and the spectra did not extend above H.

TABLE I. — *Continued.*

No.	Date.	Object.	Time.	Expos.	Slit.	Inst.	Remarks.
	1881-82.						
64	July 17	α Scorpii	10h. to	90m.	.005	11-in.	Although the night was unusually clear, there was no impression of the spectrum of α Scorpii. It may have been overlapped by the moon.
		Moon	11h. 47m.	15m.	.005		
*65	July 17	α Lyræ		47m.	.005	11-in.	
		Moon		20m.	.005	11-in.	
66	July 21	α Scorpii	9h. 44m. to	90m.	.008	11-in.	α Scorpii very faint.
		α Aquilæ	12h. 7m.	43m.	.008		
67	July 23	α Aquilæ	11h. 40m. to 12h. 2m.	22m.		11 in	At 12 h. 2 m. the sky clouded over.
68	July 24	α Scorpii	9h. 17m. to 10h. 56m.	53m.	.004	11-in.	The night was not transparent. The haze in the sky sometimes almost concealed the star
69	Aug. 8	Moon	9h. 30m. to	20m.	.003	11-in.	Notwithstanding there was a white haze in the sky, these spectra are very sharp.
		α Lyræ	10h. 46m.	49m.	003		
70	Aug. 12	α Lyræ	10h. 41m. to	44m.	.003	11-in.	Night clouded over.
		Moon	11h. 47m.	20m.	.003	11-in.	
71	Aug. 14	α Scorpii	8h. 27m. to 8h. 45m.	18m.	.003	11-in.	At 8 h. 45 m. the night became cloudy.
72	Aug. 16	α Lyræ	11h. 25m. to	46m.	.003	11-in.	After the exposure of α Lyræ, had to wait an hour for the moon to be high enough to get its spectrum.
		Moon	13h. 32m.	14m.	.003		
73	Aug. 23	α Scorpii	8h. 7m. to	64m.	.003	11-in.	The evening was misty, with clouds to the north.
		α Lyræ	10h. 8m.	41m.	.003	11-in.	
74	Mar. 23	Nebula in Orion	7h. 23m. to 9h. 14m.	111m.		11-in.	This photograph of the spectrum of the Nebula in Orion, and also the one of March 25th, were taken without a slit, and with a direct vision prism in the cone of rays from the objective, before they had reached a focus.
75	Mar. 25	Nebula in Orion	7h. 16m. to 9h. 27m.	131m.		11-in.	
76	Mar. 28	Nebula in Orion	7h. 25m. to 9h. 25m.	120m.	.017	11-in.	This spectrum of the Nebula in Orion and the one of March 30th were taken with the two-prism stellar spectroscope.
77	Mar. 30	Nebula in Orion	7h. 25m. to 9h. 25m.	120m.	.012	11-in.	
	1882	Moon		1m.	.012	11-in.	
*78	Aug. 18	α Aquilæ		50m.	.004	11-in.	This photograph was taken with a spectroscope composed of an Iceland spar prism of two inches aperture, and two quartz lenses of 15 inches focus and also two inches aperture. This spectroscope is much more transparent to the photographic rays than the one with glass lenses and prisms, but it does not give as good definition.

Several of these photographs, as stated above, were taken to the Harvard College Observatory in the spring of 1883, when the measurements described below were made. This work may be divided into three parts: first, the determination of the relative positions of the lines in the various spectra in terms of any convenient unit of length; secondly, from the known spectra of the Moon and Jupiter, a determination of the relation of these measures to wave-lengths; thirdly, a reduction of the measures of the stellar spectra to wave-lengths, and a

discussion of the results. The measures were made with the micrometer described in the Annals of Harvard College Observatory, VIII. 42. The photograph was moved under a microscope by a micrometer screw having a pitch of $\frac{1}{24}$ of an inch. By turning the screw, the lines were brought to coincide with the end of a hair in the field of view of the microscope, and the position was determined by the divided head of the screw. As is usual when examining photographs, very low powers were essential, or much of the finer detail would be lost. The best results were attained with an eyepiece and objective, each equivalent to a lens of about 2 inches focus, giving when combined a magnifying power of about fifteen diameters. The uncertainty in the position of the lines of the photograph greatly exceeded the errors of setting and the irregularities of the screw. To establish this point a measurement was made of the divisions of a glass scale constructed by Professor Rogers, in which the errors were wholly inappreciable with so low a magnifying power. Ten divisions were compared, each of which was $\frac{1}{240}$ of an inch, and equalled $\frac{1}{10}$ of a revolution of the screw. The results gave an average deviation of .0015 of a revolution, mainly due to a slight eccentricity of the head of the screw. This eccentricity amounted to about .002 of a revolution. Twelve divisions, each equal to $\frac{1}{24}$ of an inch (one turn of the screw), gave an average deviation of .002 of a revolution. These errors might be still further reduced if required, by taking additional precautions; but they are entirely insensible compared with the uncertainty in the position of the lines in the photograph. They correspond in fact to only about .02 of a ten-millionth of a millimeter in the wave-length. Throughout the work, all the settings were made by turning the screw in the direction in which the readings increase.

The reduction of the measures to wave-lengths was greatly aided by the fact that but little change was made in the spectroscopic apparatus throughout the entire investigation, and that especial care was taken to secure stiffness in its construction. A single curve could thus be used for all the reductions, at least provisionally. On the other hand, it does not seem safe to assume that, when two spectra are photographed side by side on a plate, the lines in each will have the same position.

In some of the photographs, especially in Plates 63 and 65, there is a perceptible want of coincidence between lines which are doubtless in reality of identical origin. No such deviation could be caused by any flexure of the telescope, but it might be due to flexure of the spectroscope when directed towards objects at different altitudes, or to change

of temperature of the prisms between successive exposures. It is too great to be attributed to motion of the star in the line of sight.

The measurements have all been reduced to a common zero point by subtracting the reading of the H line from each, and adding 5.000 to avoid negative readings. The H line was selected, since it is common to nearly all the spectra, and is so well marked that an accurate setting can be made on it. This more than compensates for its breadth, which renders it an inconvenient starting-point in the solar spectrum. Any correction for error in setting on this line can better be applied to the final results than to the original measurements.

Since Jupiter and the Moon shine by reflected light, it may be assumed that their spectra are identical with that of the Sun, and that the wave-lengths of the lines in their spectra may therefore be taken from a map of the solar spectrum. On account of errors in the relative prominence of different lines, errors in identification may occur in comparisons with maps made by hand. The photograph of the diffraction spectrum by Dr. Henry Draper (Amer. Journ. Sci., CVI. 401) has therefore been used as the standard to which these measurements are referred. For wave-lengths too great to be contained in this map, Angström's Map (*Recherches sur le Spectre Solaire,* Berlin, 1869) has been employed. Comparison has also been made with the map of Cornu (*Ann. de l'École Normale Supérieure,* Series II., Vol. III.), and those of Vogel (*Publicationen des astrophysikalischen Observatoriums zu Potsdam,* I. 133, II. 83). The unit employed throughout is the ten-millionth of a millimeter, and the results are only carried to single units. The best maps of the solar spectrum differ by as much as one or two of these units in the ultra violet portion, and a greater precision than this in stellar spectra is obviously at present unattainable.

To pass from screw readings to wave-lengths points were constructed with the readings of the spectra of the Moon on Plate 19 as abscissas and the corresponding wave-lengths as ordinates. This plate was selected since the lines appear to be more numerous and better defined than in the other photographs. A smooth curve was then passed through these points. The wave-lengths corresponding to each half-turn of the screw according to this curve are given in Table II., columns 1 and 2. The relation between these quantities may be very closely represented by the formula, $\lambda = 3672 + 39\,n + 4\,n^2$, in which λ denotes the wave-length, and n the number of turns of the screw. The values computed by this formula are given in the third column, and the observed minus the computed values in the fourth column.

TABLE II.

Screw Reading.	Observed.	Computed.	O. — C.	Screw Reading.	Observed.	Computed.	O. — C.
0.0	....	3672	....	5.5	4007	4008	—1
0.5	....	3693	....	6.0	4050	4050	0
1.0	....	3715	....	6.5	4093	4095	—2
1.5	3733	3740	—7	7.0	4140	4141	—1
2.0	3765	3766	—1	7.5	4188	4190	—2
2.5	3795	3795	0	8.0	4240	4240	0
3.0	3828	3825	+3	8.5	4297	4293	+4
3.5	3860	3858	+2	9.0	4350	4347	+3
4.0	3894	3892	+2	9.5	4403	4404	—1
4.5	3930	3929	+1	10.0	4466	4462	+4
5.0	3968	3967	+1				

The close agreement of the formula with observation justifies its use for reducing the observations, since, if any deviation is indicated in the results, a correction may be applied to them. Accordingly the curve represented by this formula was drawn upon a large scale, and the wave-lengths corresponding to each reading were taken from it. In Table III. a comparison is given of all the lines measured in the spectrum of the Moon and of Jupiter. The successive columns give a number for reference, and the original screw readings for the plates whose numbers head the columns, after applying the correction described above, which gives for the H line a reading 5.000 in each spectrum. The readings giving the limits to which the spectra could be traced are omitted in this table, except where they indicate known lines. In the latter case they are indicated by Italics.

TABLE III.

No.	Moon.				Jupiter.				
	21	24	63	65	35	42	43	56	57
1	1.464	....	....	....	....	....	....	....	....
2	1.716	....	....	1.758	....	....	....	....	....
3	1.861	....	....	1.888	....	....	....	....	....
4	2.151	....	....	2.123	....	....	....	....	....
5	....	....	....	2.401	....	....	....	....	....
6	2.554	....	....	2.592	....	....	....	....	....
7	2.838	....	....	2.797	....	....	....	....	....
8	3.203	*3.178*	*3.146*	3.225	*3.204*	....	*3.159*	....	....
9	3.449	....	3.544	3.513	3.547	....	....	....	....
10	....	....	3.697	3.669	3.693	....	....	3.666	3.670
11	....	....	....	3.753	....	....	....	....	....
12	3.882	3.897	....	3.942	3.858	....	3.827	....	....
13	4.168	....	4.151	4.179	4.214	....	....	4.148	4.145
14	4.534	4.558	4.556	4.548	4.557	*4.531*	4.538	4.531	4.544

TABLE III. — *Continued.*

No.	Moon.				Jupiter.				
	21	24	63	65	35	42	43	56	57
15	....	....	....	4.648	....	....	....	....	....
16	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
17	....	....	....	....	5.198	....	....	....	....
18	....	....	5.345	....	5.353	....	....	....	5.337
19	....	....	5.475	5.464	5.496	....	....	5.476	5.468
20	5.804	....	5.786	5.787	5.814	....	5.780	5.805	5.768
21	....	....	5.946	5.942	5.964	....	5.959	5.951	5.944
22	....	....	6.161	6.162	6.187	....	6.151	6.160	6.063
23	....	....	....	....	....	....	....	....	6.288
24	....	....	....	6.326	6.337	....	6.320	6.335	6.317
25	6.599	6.592	6.577	6.581	6.605	6.578	6.584	6.579	6.576
26	....	6.661	....	....	....	....	....	....	....
27	....	....	6.925	6.919	6.944	....	6.898	6.921	6.918
28	....	....	....	....	....	....	....	....	6.985
29	....	....	7.046	7.038	7.044	....	....	7.042	7.026
30	....	7.143	7.189	7.171	7.178	....	....	7.192	7.163
31	7.383	7.406	7.368	7.326	7.369	....	7.348	7.359	7.330
32	....	....	....	....	7.500	....	....	....	7.493
33	7.644	....	7.637	7.606	7.616	....	....	7.616	7.610
34	....	....	....	....	....	....	....	....	7.707
35	....	....	....	7.755	7.775	....	....	7.783	7.776
36	7.923	7.890	7.885	7.863	7.881	....	7.874	7.885	7.874
37	....	7.990	7.985	7.983	7.972	....	....	7.991	7.972
38	....	....	8.087	8.069	8.097	....	....	8.104	8.097
39	....	....	8.211	8.199	8.194	....	....	8.205	8.202
40	....	8.334	8.317	8.295	8.304	....	8.331	8.324	8.311
41	....	....	8.482	....	8.473	....	....	8.480	8.456
42	....	....	8.593	8.564	8.577	....	8.596	8.578	8.568
43	8.678	8.680	8.661	8.632	8.648	8.636	8.644	8.654	8.660
44	....	....	8.784	8.768	8.785	....	8.798	8.791	8.785
45	....	8.925	8.927	8.910	8.923	8.938	8.925	8.929	8.923
46	....	9.043	9.028	....	....	....	....	9.040	9.032
47	....	....	9.222	9.222	9.204	....	....	....	....
48	9.353	9.347	9.300	....	9.300	....	9.322	9.292	9.294
49	....	....	9.494	9.440	9.472	....	....	9.474	9.465
50	....	....	....	....	9.547	....	....	9.566	9.556
51	....	....	....	....	9.677	....	....	9.714	9.706
52	9.936	9.944	9.905	9.891	9.867	....	9.898	9.881	9.880
53	....	....	....	....	10.059	....	....	10.082	10.073
54	10.511	10.427	....	10.423	10.416	....	....	10.441	10.338
55	....	....	....	....	....	....	....	10.621	10.586

In Table IV. these measures are compared. The first column gives the same number for reference as in Table III. The second column gives the wave-lengths of the lines in the solar spectrum, with which the lines here measured are assumed to be identical. Each measurement is reduced to wave-lengths by the formula given above. The residuals found by subtracting the assumed wave-lengths from these are given in the subsequent columns. Each plate is designated by its appropriate number.

TABLE IV.

No.	Wave Length.	Moon.				Jupiter.				
		21	24	63	65	35	42	43	56	57
1	3736	0	....	....	....	....	....	....	....	....
2	3750	0	....	....	+2	....	....	....	....	....
3	3759	—1	....	....	+1	....	....	....	....	....
4	[3774]	[+1]	....	....	[—1]	....	....	....	....	....
5	3786	....	....	....	+3	....	....	....	....	....
6	3801	—3	....	....	0	....	....	....	....	....
7	3816	—1	....	....	—3	....	....	....	....	....
8	3841	—3	—5	—7	—1	—3	....	—5	....	....
9	3859	—5	....	+2	0	+2	....	....	....	....
10	3872	....	....	—1	—3	—2	....	....	—3	—3
11	3878	+1	+2	....	—3	—1	....	—3	....	....
12	3888			....	0		....		....	....
13	3905	0	....	—2	0	+3	....	....	—2	—2
14	3933	—1	+1	+1	0	+1	—1	—1	—2	—1
15	3943	....	....	....	—3	....	....	....	....	....
16	3967	0	0	0	0	0	0	0	0	0
17	3988	....	....	....	....	—5	....	....	....	....
18	3908	....	....	—3	....	—2	....	....	....	—4
19	4005	....	....	+1	0	+3	....	....	+1	0
20	4032	+1	....	0	0	+2	....	—1	+1	—2
21	4045	....	....	0	0	+2	....	+1	0	0
22	4063	....	....	+1	+1	+3	....	0	+2	—7
23	4071	....	....	....	....	....	....	....	....	0
24	4077	....	....	....	+2	+3	....	+1	+3	+1
25	4101	+3	+3	+1	+2	+4	+1	+2	+2	+1
26	4118	....	—3	....	....	....	....	....	....	....
27	4133	....	....	+1	+1	+3	....	—1	+1	0
28	4138	....	....	....	....	....	....	....	....	+2
29	4143	....	....	+2	+2	+2	....	....	+2	—3
30	4155	....	0	+4	+3	+3	....	....	+5	+2
31	4172	+6	+3	+4	+1	+5	....	+3	+4	+1
32	4187	....	....	....	....	+3	....	....	....	+2
33	4201	+4	....	+3	0	+1	....	....	+1	0
34	4210	....	....	....	....	....	....	....	....	+1
35	4215	....	....	....	+2	+4	....	....	+5	+4
36	4226	....	+5	+4	+2	+4	....	+4	+4	+3
37	4236	—1	+6	+5	+5	+4	....	....	+6	+4
38	4250	....	....	+2	+1	0	....	....	0	0
39	4260	....	....	+6	+5	0	....	....	+1	+1
40	4271	....	—2	—4	—6	+1	....	+4	+3	+2
41	4289	....	....	+2	....	+1	....	....	+2	0
42	4301	....	....	+2	—1	0	....	+3	+1	0
43	4312	0	+1	—1	—5	—3	—4	—3	—2	—2
44	4324	....	....	0	—2	0	....	+1	+1	0
45	4339	....	0	0	—2	0	+1	0	+1	0
46	4351	....	+1	—1	....	....	....	....	0	0
47	4375?	....	....	—3	—2	—5	....	....	....	....
48	4383	+3	+3	—2	....	—3	....	0	—3	—3
49	4404	....	....	—1	—3	—4	....	....	—4	—5
50	4414	....	....	....	....	—5	....	....	—3	—3
51	4424	....	....	....	....	—1	....	....	+5	+4
52	4454	+2	+3	—2	—3	—7	....	—3	—7	—7
53	4483	....	....	....	....	—12	....	....	—9	—11
54	4530	—3	—14	....	—13	—15	....	....	—12	—26
55	4549	....	....	....	....	....	....	....	—9	—13

Plate 42 was one of the first to be measured, and only the most conspicuous lines were observed. This was done with the intention of determining the scale from a few well-defined lines. It was afterwards deemed better to employ all the lines visible on each plate for this purpose. No marked line in the solar spectrum satisfactorily represents No. 4 of Table IV. Nos. 3 and 4, 5 and 6, and 7 and 8, are designated in the original record as the limits of transparent bands in the negatives, that is, of dark bands in the spectrum. Nos. 11 and 12 appeared as a broad dark band, whose edges were observed in Plate 65, and its centre in Plates 21, 24, 35, and 43. No. 28 is recorded in Plate 57 as the centre of the band extending from 27 to 29. No. 47 is not well identified. The photographs of the solar spectrum indicate a line having $\lambda = 4375$ as the most conspicuous in this vicinity.

The residuals in Table IV. must next be examined, to see if they indicate any systematic deviation, or if any correction should be applied to the wave-lengths as deduced by the formula $\lambda = 3672 + 39n + 4n^2$.

TABLE V.

λ	Moon.				Jupiter.				All.		
	No.	$\Sigma+$	$\Sigma-$	$\frac{\Delta\pm}{n}$	No.	$\Sigma+$	$\Sigma-$	$\frac{\Delta\pm}{n}$	$\frac{\Delta\pm}{n}$	Curve.	$\frac{\Sigma\pm}{n}$
3700	3	2	0	+0.7	0	..	...	.....	+0.7	+0.5	0.7
3800	11	4	24	−1.8	2	0	8	− 4.0	−2.0	−1.0	2.4
3900	17	7	18	−0.6	14	6	21	− 1.1	−0.8	−0.8	1.5
4000	12	2	3	−0.1	19	10	14	− 0.2	−0.2	−0.1	1.3
4100	12	19	8	+0.9	22	33	11	+ 1.0	+1.0	+1.0	1.5
4200	20	67	1	+3.3	26	73	0	+ 2.8	+3.0	+2.2	1.9
4300	17	16	21	−0.3	28	23	14	+ 0.3	+0.1	+0.7	1.6
4400	9	7	17	−1.1	16	9	39	− 1.9	−1.6	−2.6	2.2
4500	7	5	35	−4.3	12	0	132	−11.0	−8.5	−7.4	4.6

In Table V. they are arranged in groups extending from 3750 to 3850, 3850 to 3950, etc. The first column gives the approximate mean wave-length of each group, and the next four columns give for the Moon the number of measurements included in each group, the sum of the positive and the sum of the negative residuals, and their algebraic mean. The next four columns give the corresponding quantities for Jupiter. The last three columns relate to the observations of the Moon and Jupiter, without distinction. The first of these columns gives the algebraic mean of all the residuals, and indicates the observed deviation from the computed wave-lengths. A curve was drawn to represent this deviation, and its ordinates are given in the next column. Finally, the residuals were all corrected by means of this curve according to the system indicated in Table VI., and the arithmetical mean of

the residuals is given in the last column. The residuals of the H line, being all rendered zero by the method of reduction, are not included in the last column, although retained in the preceding columns.

The average deviation of all the measures, including the faint, as well as the more marked lines, is only 1.7, or less than $\frac{1}{4}$ of the interval between the sodium lines. Less accuracy was attained in measuring the lines near the ends of the spectrum, owing to the faintness of the photographic effect. In many cases the last lines were marked as "very doubtful." This error was increased for the lines of greater wave-length by the fact that a given distance, as one division of the screw, represents a change in wave-length of double the corresponding amount at the other end of the spectrum. Without the correction indicated by this table, the average deviation of the individual results would be 2.7. Table VI. gives the correction indicated in each portion of the spectrum derived from Table V. The first column gives the limiting wave-lengths within which the corrections in the second column should be applied. The sign of the corrections is such that they are to be added to the results derived from the formula.

TABLE VI.

Limits.	Correction.	Limits.	Correction.
3700 to 3757	0	4398 to 4421	+ 3
3758 " 3952	+1	4422 " 4443	+ 4
3953 " 4054	0	4444 " 4464	+ 5
4055 " 4126	—1	4465 " 4484	+ 6
4127 " 4264	—2	4485 " 4503	+ 7
4265 " 4308	—1	4504 " 4521	+ 8
4309 " 4342	0	4522 " 4539	+ 9
4343 " 4371	+1	4540 " 4556	+10
4372 " 4397	+2		

Measurements of these spectra may then be converted into wave-lengths by applying to the readings of the curve described above the corrections of Table VI. Thus the measurement 2.618 gives by the curve 3802, but since this falls between 3758 and 3952, we must apply the correction +1. The wave-length corresponding to 2.618 will then be 3803. When the same lines are observed in several spectra, the correction may be applied to their mean, instead of to the separate readings.

Plates 21, 23, and 24 were taken with the 12-inch refractor, and accordingly the spectra are narrow in the violet and wide in the blue portions. For Plates 63, 65, 73, and 78 the 11-inch telescope was

employed. As this instrument is corrected for the photographic rays, the spectra are of nearly uniform width, becoming slightly narrower at the ends. The other plates measured were obtained with the 28-inch reflector. As such an instrument is free from chromatic aberration, the spectra are of uniform width.

The measurements of the various spectra are given in Table VII. The first column gives a number for reference, followed by the measures of the corresponding lines in the columns headed by the number of the plates. The second part of each portion of the table gives the mean wave-length of each line, found by reducing the corresponding measures to wave-lengths by means of the curve and correcting by Table VI. The last columns give the residuals found by subtracting the mean from the individual values. So many measures were made of *α Lyræ* that the second part of the table is here separated from the first. In Plate 73 the residuals are omitted, since the scale for this plate differs from that of the others. In the spectra of *α Scorpii* on Plate 73 the H line is not visible. The original readings are therefore given in Table VII.

TABLE VII.

α AQUILÆ.

No.	41	42	56	λ	41	42	56
1	*1.517*	*1.470*	....	3738	+1	−1	....
2	1.793	1.765	....	3754	0	−1	....
3	2.104	2.089	....	3773	0	−1	....
4	2.539	2.542	....	3798	0	0	....
5	3.129	3.150	....	3835	−1	+1	....
6	3.904	3.914	3.929	3887	−1	0	+1
7	4.540	4.541	4.552	3933	0	0	+1
8	5.000	5.000	5.000	3967	0	0	0
9	....	5.770	....	4030	....	0	....
10	6.576	6.573	6.595	4102	−1	−1	+1
11	8.936	9.912	8.937	4339	−1	+1	+1

α LYRÆ.

No.	26	30	34	45	46	63	65	73
12	*1.308*	....	....	....	....	....	....	....
13	1.520	*1.503*	*1.525*	*1.422*	....	....	....	*0.863*
14	1.787	1.772	1.839	1.735	....	....	*1.733*	1.211
15	2.114	2.116	2.156	2.068	....	....	....	1.605
16	2.554	2.573	2.580	2.504	*2.539*	....	2.563	2.121
17	3.121	3.128	3.154	3.118	3.152	3.138	3.149	2.890
18	3.925	3.918	3.954	3.914	3.900	3.911	3.935	3.732
19	4.517	....	4.536	4.502	4.519	4.509	4.544	4.437
20	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
21	6.565	6.562	6.560	6.569	6.586	6.575	6.559	6.832
22	8.882	8.893	8.881	8.916	8.922	8.918	8.913	9.508
23	....	....	....	....	....	....	....	13.595

TABLE VII. — *Continued.*

a Lyræ.

No.	λ	26	30	34	45	46	63	65
12	3728	0	....	....	....	....	....	....
13	3738	+1	0	+1	−4	....	....	....
14	3753	+1	0	+4	−2	....	....	−2
15	3773	0	0	+3	−2	....	....	....
16	3799	0	+1	+2	−3	−1	....	+1
17	3835	−1	−1	+1	−2	+1	0	+1
18	3888	0	−1	+2	−1	−2	−1	+1
19	3932	0	....	+1	−3	0	−1	+1
20	3967	0	0	0	0	0	0	0
21	4102	−1	−1	−1	0	+1	0	−1
22	4337	−2	−1	−3	+1	+2	+1	+2
23	4861	....	....	....	....	....	....	....

a Aurigæ.

No.	21	43	57	λ	21	43	57
24	....	3.600	....	3865	....	0	....
25	*4.532*	4.528	*4.545*	3932	0	0	+1
26	5.000	5.000	5.000	3967	0	0	0
27	....	5.494	....	4008	....	0	....
28	....	5.832	5.770	4032	....	+3	−2
29	....	5.970	5.918	4045	....	+2	−2
30	....	6.323	6.281	4076	....	+2	−2
31	6.588	6.600	6.568	4102	0	+1	−2
32	....	6.929	6.978	4134	....	−2	+8
33	....	7.171	7.160	4156	....	0	−1
34	7.347	7.392	7.328	4174	−1	+3	−3
35	7.627	7.644	7.549	4199	+3	+4	−6
36	....	7.777	7.737	4214	....	+3	−2
37	7.910	7.881	7.854	4228	+3	0	−2
38	....	....	7.985	4239	....	....	0
39	....	....	8.090	4251	....	....	0
40	....	8.202	8.174	4262	....	+1	−2
41	....	8.357	8.290	4269	....	−1	+1
42	....		8.463	4287	....		+1
43	....	....	8.567	4299	....	....	0
44	8.638	8.660	8.626	4307	0	+2	−1
45	....	....	8.756	4321	....	....	0
46	8.976	8.940	8.902	4341	+4	0	−4
47	....	9.091	[8.801]	4358	....	0	[+1]
48	....	9.342	9.259	4382	....	+5	−4
49	....	....	9.450	4401	....	....	0
50	....	9.747	....	4438	....	0	....
51	9.948	9.952	....	4462	0	0	....
52	....	10.187	....	4493	....	0	....
53	10.390	10.456	....	4524	−5	+4	....
54	....	10.641	....	4552	....	0	....

The record of No. 47, Plate 57, gives a reading of 8.801; but this is evidently wrong, since it is less than No. 46. It should perhaps have been 9.101, which gives a residual +1.

TABLE VII. — *Continued.*

a Bootis.

No.	23	24	32	λ	23	24	32
55	....	....	*2.892*	3819	....	....	0
56	....	....	3.245	3842	....	....	0
57	....	....	3.508	3859	....	....	0
58	....	*3.765*	3.816	3878	....	—2	+2
59	....	....	4.122	3902	....	....	0
60	*4.532*	4.552	4.554	3938	—1	+1	+1
61	5.000	5.000	5.000	3967	0	0	0
62	....	....	5.347	3995	....	....	0
63	5.503	....	5.480	4007	+1	....	—1
64	5.830	....	5.801	4034	+1	....	—1
65	5.976	....	5.938	4046	+2	....	—1
66	6.085	....	6.113	4057	—1	....	+2
67	....	....	6.261	4072	....	....	0
68	6.363	6.345	6.324	4080	+1	0	—2
69	6.388	....	....	4084	0	....	....
70	6.530	6.561	6.540	4098	—1	+2	0
71	....	....	6.787	4116	....	....	0
72	....	....	6.917	4131	....	....	0
73	7.088	7.098	7.089	4146	+1	+2	—3
74	7.300	7.380	7.385	4172	—4	+4	0
75	....	....	7.612	4199	....	....	0
76	7.716	....	7.742	4212	—2	....	+1
77	7.880	7.827	7.855	4224	—1	—2	+2
78	7.938	7.932	7.965	4234	0	0	+1
79	8.162	....	8.100	4254	+1	....	—2
80	8.384	....	8.299	4275	+4	....	—4
81	8.647	8.615	8.613	4306	+2	—1	—2
82	....	....	8.795	4325	....	....	0
83	8.875	....	8.890	4334	0	....	+1
84	8.993	....	9.018	4349	—2	....	+1
85	9.274	9.263	9.292	4383	—4	+5	—2
86	9.551	....	9.460	4407	+6	....	—5
87	9.927	9.969	9.880	4460	0	+5	—6
88	....	....	10.160	4489	....	....	0
89	10.417	10.382	10.388	4520	+3	—2	—1

a Scorpii.

No.	39	48	73	λ	39	48
90	....	....	50.449	3976	....	....
91	....	....	52.126	4099	....	....
92	6.951	6.876	....	4132	+4	—4
93	....	7.175	....	4156	....	0
94	7.345	7.226	52.988	4169	+3	—8
95	7.542	7.552	53.346	4202	—9	—8
96	....	7.718	53.486	4212	....	—2
97	....	....	53.632	4224	....	....
98	....	7.927	53.720	4238	....	0
99	....	....	53.804	4242	....	....
100	8.057	8.058	53.942	4253	—5	—5
101	8.308	8.230	54.122	4270	+1	—6
102	....	8.390	54.221	4280	....	0

TABLE VII. — *Continued.*

a Scorpii.

No.	89	48	73	λ	89	48
103	8.477	....	54.304	4291	—1	....
104	8.598	8.543	54.393	4296	+7	+1
105	....	8.650	54.548	4312	....	—2
106	....	....	54.658	4320	....	....
107	....	....	54.718	4328	....	....
108	8.925	8.925	54.811	4336	+3	+3
109	....	....	54.864	4342	....	....
110	....	....	54.932	4349	....	....
111	....	9.087	55.019	4360	....	—3
112	....	....	55.078	4366	....	....
113	....	....	55.150	4374	....	....
114	....	....	55.216	4382	....	....
115	9.591	9.535	55.474	4410	+8	+1
116	....	9.754	55.718	4440	....	—2
117	....	....	55.787	4448	....	....
118	....	10.033	55.921	4464	....	+4
119	10.111	....	56.037	4477	+4	....
120	....	....	56.138	4490	....	....
121	....	....	56.327	4513	....	....
122	....	10.517	56.522	4539	....	—5
123	....	....	56.574	4544	....	....
124	10.865	....	56.751	4567	+12	....
125	....	....	57.148	4617	....	....
126	....	....	57.475	4658	....	....
127	....	....	57.610	4676	....	....

The measures of the different photographs of the first four stars agree as well as could be anticipated. The accidental errors are small considering the extreme faintness of many of the images. No large systematic deviations appear, except in the case of *a Lyræ*, Plate 73, to which reference has already been made (p. 253). Small systematic errors are, however, perceptible in other plates, as in No. 34, where the residuals change from positive to negative, and in No. 45, where they change from negative to positive. They will not, however, sensibly affect the final result, and scarcely justify the application of a separate correction.

A comparison of the lines in *a Aquilæ* * and *a Lyræ* is given in

* A peculiarity of the spectrum of *a* Aquilæ deserves special mention. Besides the intense broad hydrogen bands which characterize the spectrum of *a* Lyræ and similar stars, it exhibits a multitude of very fine lines, which are easily seen between G and H in several of the plates, but are too delicate to be satisfactorily measured. Dr. Draper considered these fine lines very important, as showing that this star — Altair — should be considered a sort of intermediate link between *a* Lyræ and Sirius on one side, and Capella and the Sun on the other. — C. A. Y.

Table VIII. The columns give a number for reference, the result for *a Aquilæ* taken from Table VII., that for *a Lyræ*, and that given by Dr. Huggins for all stars of this class.

TABLE VIII.

No.	Dr. Draper.		Dr. Huggins.		Dr. Draper.		Dr. Huggins.
	a Aquilæ.	a Lyræ.	Type I.		a Aquilæ.	a Lyræ.	Type I.
1	....	....	3699	8	3835	3835	3834
2	....	....	3708	9	3887	3888	3887
3	....	3728	3717	10	3933	3932	....
4	3738	3738	3730	11	3967	3967	3968
5	3754	3753	3745	12	4030	....	....
6	3773	3773	3768	13	4102	4102	4101
7	3798	3799	3795	14	4339	4337	4340

The distinctive feature of these spectra is a series of broad dark lines at regular intervals. The lines of greater wave-length appear to coincide with the hydrogen lines, and the interval between the successive lines continues to diminish with the wave-length. Twelve of these lines are photographed by Dr. Huggins. To these we should add the lines F (4861) and C (6562), which are beyond the limits of the photograph. The first and second lines are not contained in Dr. Draper's photographs, as his plates were not sensitive to rays of such short wave-length. Line 10, which appears to coincide with K of the solar spectrum, is as strong as the others in *a Aquilæ*, but in every photograph of *a Lyræ* was marked as faint. In one case in Plate 30 it was overlooked. This photograph was over-exposed in this part of the spectrum, but a more careful examination shows that the line is probably present. Line 10 was only noticed in Plate 42.

The resemblance of the spectrum of *a Aurigæ* to that of the Sun has already been noted; *a Bootis* appeared to belong to the same class, but the identity of the lines was not perceived until the measurements had been reduced. It then became obvious that this star also has a spectrum closely resembling the Sun. The comparison is made in Table IX. The first and second columns are the same as in Table IV., and give a number for reference and the wave-length of the lines in the solar spectrum. The next column gives the number of plates of the Moon and Jupiter, on which each line was measured. It therefore gives a sufficiently good comparison of the relative prominence of each line. The next four columns give for the *Moon*, for *Jupiter*, for *a Aurigæ*, and for *a Bootis*, the mean of the measured wave-length minus the wave-length given in the second column.

TABLE IX.

No.	Wave Length.	No.	Moon.	Jupiter.	α Aurigæ.	α Bootis.
1	3736	1	0	....	....	....
2	3750	2	+1	....	....	....
3	3759	2	+1	....	....	....
4	[3774]	2	+1	....	....	....
5	3786	1	+4	....	....	....
6	3801	2	−1	....	....	....
7	3816	2	−1	....	....	+3
8	3841	4	−3	....	....	+1
9	3859	4	0	+3	....	0
10	3872	5	−1	−2	....	....
11	3878	5	+4	+3	....	0
12	3888	5	+1	+2	....	....
13	3905	6	0	+1	....	−3
14	3933	9	+1	0	−1	0
15	3943	1	−2	....	....	....
16	3967	9	0	0	0	0
17	3988	1	....	−5	....	....
18	3998	3	−3	−3	....	−3
19	4005	5	+1	+1	+3	+2
20	4032	7	0	0	0	+2
21	4045	6	0	+1	0	+1
22	4063	6	0	−1	....	−6
23	4071	1	....	−1	....	−1
24	4077	5	+1	+1	−1	+8
25	4101	9	+1	+1	+1	−8
26	4118	1	−9	....	....	−2
27	4133	6	0	0	+1	−2
28	4138	1	....	0	....	....
29	4143	5	0	−2	....	+3
30	4155	6	0	+1	+1	....
31	4172	8	+3	+1	+2	0
32	4187	2	....	0	....	....
33	4201	6	0	−1	−2	−2
34	4210	1	....	−1	....	+2
35	4215	4	0	+2	−1	....
36	4226	7	+2	+2	+2	−2
37	4236	7	+2	+3	+8	−2
38	4250	5	0	−2	+1	+4
39	4260	5	+4	−1	+2	....
40	4271	7	−5	+1	−2	+4
41	4289	4	+1	0	−2	....
42	4301	6	−1	0	−2	....
43	4312	9	−1	−3	−5	−6
44	4324	6	−1	0	−3	+1
45	4339	8	−1	0	+2	−5
46	4351	4	+1	+1	+7	−2
47	4375?	8	0	−3	....	....
48	4388	7	+3	0	−1	0
49	4404	5	−1	−1	−3	+3
50	4414	3	....	−1	....	....
51	4424	3	....	+7	+14	....
52	4454	8	+5	−1	+ 8	+6
53	4483	3	....	−5	+10	+6
54	4530	6	+1	−9	−6	−10
55	4549	2	....	−1	+3	....

The only line omitted in this table which was noted in the spectra of *a Aurigæ* or *a Bootis* is No. 69 of Table VII. This line was measured in Plate 23 as one edge of a dark band in the negative, No. 70, or *h*, forming the other side. Its wave-length may therefore be taken as about 4090. This is the bright band noted on page 242. The same phenomenon is shown in Plate 24, and even better in Plate 32. It is also noticeable, though in a less marked manner, in the solar spectrum, as is shown in the photographs of Jupiter and of the Moon.

Not only do the lines of *a Aurigæ* and *a Bootis* appear to coincide with those of the Sun in position, but their relative intensity seems to be nearly the same. Of the twelve lines seen in at least seven of the nine spectra of the Moon and Jupiter, every one is contained in the spectra of both *a Aurigæ* and *a Bootis*. Of the fifteen lines which are so faint as to be contained in but one or two of the spectra of the Moon or Jupiter, only four are contained in the spectrum of *a Bootis*, and but one in that of *a Aurigæ*. The evidence afforded by these photographs, therefore, points very strongly to the conclusion that the spectra of these stars, and consequently their constitution, are the same as that of our Sun.

The measurements of *a Scorpii* are much less satisfactory than those of the other stars. Plate 73 gives a large number of lines, but the scale of this plate, as already stated, differs from that of the others. Fortunately, *a Lyræ* was photograped on the same plate, and a curve was accordingly constructed with the measurements of the lines of this star as abscissas, and the wave-lengths taken from the measures of the other plates as ordinates. By this curve the measures of *a Scorpii* were reduced. Plates 39 and 48 were taken with a wide slit, and the lines are indistinct. A satisfactory comparison could scarcely be made without preparing enlarged paper positions, and marking on them the points measured. This seems scarcely advisable, considering the superiority of Plate 73. The large residuals render the identification uncertain in some cases, since any line would fall near one of those in Plate 73. The correspondence is much less marked than in the other stars.

A comparison of the measures of the various plates is given in Table X. The first column gives the number of the plate; the second, the name of the object photographed; the third, the number of measures made, that is, the number of points of the spectrum noted; and the fourth column gives the quantity subtracted from each of the measures to reduce them to the same zero. The measures of the ends of the spectra are given in the next two columns, followed by the reduced value in wave-lengths.

TABLE X.

No. of Plate.	Object.	No. of Measures.	Zero.	Measures.		Wave-Lengths.	
				Beginning.	Ending.	Beginning.	Ending.
21	α Aurigæ	11	45.184	*4.532*	11.374	3932	4650
	Moon	24	45.173	0.951	11.898	3708	4737
23	α Bootis	24	45.281	*4.532*	11.465	3932	4664
24	α Bootis	15	45.341	*3.765*	11.334	3876	4641
	Moon	18	45.184	*3.178*	12.074	3836	4749
26	α Lyræ	12	51.328	*1.308*	12.714	3728	4843
30	α Lyræ	10	48.686	*1.503*	13.065	3738	4896
32	α Bootis	36	45.032	*2.892*	12.419	3819	4799
35	Jupiter	42	45.100	*3.204*	12.091	3838	4751
34	α Lyræ	11	49.798	*1.525*	12.215	3789	4770
39	α Scorpii	12	41.272	4.870	11.368	3957	4650
41	α Aquilæ	11	68.613	*1.517*	11.179	3789	4622
42	α Aquilæ	12	53.313	*1.470*	12.264	3737	4776
	Jupiter	6	53.308	*4.531*	11.888	3836	4721
43	α Aurigæ	26	46.215	*3.600*	11.821	3865	4713
	Jupiter	20	46.181	*3.159*	12.295	3932	4780
45	α Lyræ	11	47.572	*1.422*	11.970	3734	4735
46	α Lyræ	8	45.517	2.589	11.680	3798	4694
48	α Scorpii	19	43.441	6.691	11.209	4113	4628
56	α Aquilæ	7	45.489	3.310	11.546	3846	4674
	Jupiter	37	45.551	3.230	12.126	3841	4755
57	Jupiter	12	44.848	3.476	11.385	3857	4651
	α Aurigæ	25	44.862	*4.545*	12.338	3932	4786
63	α Lyræ	8	45.123	2.657	11.599	3805	4681
	Moon	34	45.032	*3.146*	12.094	3834	4750
65	α Lyræ	9	45.040	*1.733*	12.001	3751	4738
	Moon	42	44.991	1.525	12.045	3739	4744
73	α Scorpii	37	45.316	5.133	13.272	3976	4820
	α Lyræ	11	45.316	*0.863*	*13.595*	3723	4861
78	α Aquilæ	10	43.546	0.080	24.069	....	....

The readings in the sixth column cannot be reduced to wave-lengths directly, since they fall outside of the limits of Table VI. The curve on which this table was based was accordingly prolonged, and a curve drawn giving for large readings the corresponding wave-lengths. In the columns of Table XI. these values are given for intervals of half a turn of the micrometer screw.

TABLE XI.

No. of Turns.	Wave-Length.	No. of Turns.	Wave-Length.
10.0	4468	12.0	4737
10.5	4532	12.5	4811
11.0	4597	13.0	4886
11.5	4666		

The readings in the fourth column of Table X. serve to test the flexure of the spectroscope by showing whether the zero was the same

in the various spectra on the same plate. A portion of the difference may be due to the impossibility of setting the lines exactly at right angles to the micrometer screw, and in some cases, as in Plate 56, to a possible movement of the plate between the measures of the two spectra. This cannot account for all the difference, however, since in several cases it is obvious to the eye. The difference in wave-length would vary in different parts of the spectrum, but an idea of its magnitude may be inferred by the rule that one turn of the screw near the H line corresponds to a change of 80 in the wave-length. The two spectra are thus displaced by several units, an amount which the residuals show is quite beyond the accidental errors of measurement. The adoption of a new zero for each spectrum thus appears to have been entirely justified.

From the last two columns of Table X. we see that the plates are sensitive to rays of light of wave-lengths 3750 to 4800, that is, from M nearly to F. When the light is intense, the spectra extend beyond these limits. F is photographed in Plate 73, and in Plate 21 a line marked "very doubtful" was observed at 3708. It was not included in Tables III. and IV., as it probably only indicates the beginning of the spectrum.

To secure entire independence in the results, the measures were completed before the reductions were begun. The lines in each plate were measured without comparison with any map, and no search was made for lines which appeared to be wanting. When two similar spectra were photographed side by side, as in Plate 21, care was taken to cover one when measuring the other. Under these circumstances, the agreement in the measures of several plates is strong evidence of the identity of the spectra.

IX.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON MUCOPHENOXYBROMIC ACID.

By Henry B. Hill and Edward K. Stevens.

Presented May 29, 1883.

The products which are formed when mucobromic acid is treated with a large excess of baric hydrate, have already been described by O. R. Jackson and one of us.* Formic and dibromacrylic acids were found to be the first products of this reaction, although even in the cold a part of the dibromacrylic acid was further converted into brompropiolic acid. Later experiments undertaken with the view of avoiding this secondary decomposition, showed that an entirely different reaction ensued when the conditions were so modified that the solution was at no time strongly alkaline.† The chief product formed in this case was easily found to be an acid containing four atoms of carbon and one of bromine; but the determination of its constitution proved to be a matter of more difficulty, and a description of it must therefore be postponed until it can be further studied. Since it seemed possible that sodic ethylate or potassic phenylate might react upon mucobromic acid and yield similar products, whose constitution could more easily be determined, we turned our attention in this direction. Although we have been unable to obtain any such products by the action of sodic ethylate, potassic phenylate has given us well-defined products containing the phenoxyl group.

Mucophenoxybromic Acid.

Potassic phenylate acts upon potassic mucobromate in aqueous solution at ordinary temperatures; but the isolation of the potassic mucophenoxybromate thus formed is somewhat difficult, and we have

* These Proceedings, Vol. XVI. (N. S. VIII.) p. 188.
† *Loc. cit.*, p. 204.

not been able to obtain uniform results in our various preparations. We have found it advantageous to use a large excess of potassic phenylate, and to add also potassic hydrate in quantity sufficient to neutralize the mucobromic acid taken. We usually have dissolved 25 grms. of crystallized phenol and 17.5 grms. of ordinary potassic hydrate in 30 grms. of water, and after the solution is well cooled, have added 20 grms. of mucobromic acid. After the lapse of a short time small compact rhombic crystals of the new potassium salt begin to separate, and the reaction is ordinarily completed in less than an hour. The crystals should then be collected at once, drained by the pump, and washed with a little cold water. Hydrochloric acid added to an aqueous solution of the salt then precipitates mucophenoxybromic acid in clustered needles, which, when dried over sulphuric acid, gave the following results: —

I. 0.2156 grm. substance gave on combustion 0.3486 grm. CO_2 and 0.0525 grm. H_2O.

II. 0.2250 grm. substance gave 0.1564 grm. AgBr.

III. 0.2168 grm. substance gave 0.1504 grm. AgBr.

	Calculated for $C_4H_2(OC_6H_5)BrO_3$.	Found. I.	II.	III.
C	44.28	44.11		
H	2.58	2.71		
Br	29.52		29.58	29.52

When crystallized from hot water, mucophenoxybromic acid forms small flat prisms concentrically grouped, which melt at 104–105°. The acid is readily soluble in hot water, sparingly in cold; readily soluble in alcohol or ether, soluble in hot benzol or chloroform, and almost insoluble in carbonic disulphide or ligroin. An aqueous solution of the acid reduces silver oxide on warming, and gives with ferric chloride a whitish precipitate.

Potassic Mucophenoxybromate. $KC_4H(OC_6H_5)BrO_3$. The salt obtained by the action of potassic phenylate upon mucobromic acid was recrystallized several times from warm water. It formed then oblique tabular crystals quite soluble even in cold water. The salt is more stable in aqueous solution than the corresponding mucobromate, and yet suffers quite rapid decomposition at temperatures near 100°. The salt dried by exposure to the air contains no water of crystallization.

I. 0.4314 grm. of the salt gave on ignition with H_2SO_4 0.1227 grm. K_2SO_4.

II. 0.4430 grm. of the salt gave on ignition with H_2SO_4 0.1255 grm. K_2SO_4.

	Calculated for $KC_4H(OC_6H_5)BrO_3$.	Found. I.	II.
K	12.65	12.76	12.72

Baric Mucophenoxybromate. $Ba(C_4H(OC_6H_5)BrO_3)_2 3H_2O$. This salt was obtained by neutralizing a cold aqueous solution of the acid with baric carbonate, and allowing the solution thus obtained to evaporate spontaneously. It separated in leafy rhombic crystals, which were very soluble in water. On warming the solution decomposition ensued. The air-dried salt contained three molecules of water, one of which it lost over sulphuric acid, the rest at 100°.

I. 0.8147 grm. of the air-dried salt lost over H_2SO_4 0.0213 grm. H_2O, and in addition 0.0403 grm. at 100°.
II. 0.7863 grm. of the air-dried salt lost over H_2SO_4 0.0201 grm. H_2O, and in addition 0.0397 grm. at 100°.

	Calculated for $Ba(C_4H(OC_6H_5)BrO_3)_2 3H_2O$.	Found. I.	II.
H_2O	2.46	2.61	2.56
$3\ H_2O$	7.39	7.56	7.61

0.4628 grm. of the salt dried at 100° gave on ignition with H_2SO_4 0.1599 grm. $BaSO_4$.

	Calculated for $Ba(C_4H(OC_6H_5)BrO_3)_2$.	Found.
Ba	20.23	20.32

When treated with an excess of an alkaline hydrate, mucophenoxybromic acid, like mucobromic, is decomposed, and yields a substituted acrylic acid together with formic acid.

Phenoxybromacrylic Acid.

We have found it most convenient to dissolve equal weights of potassic hydrate and potassic mucophenoxybromate each in their own weight of water, and to mix the hot solutions. On cooling, potassic phenoxybromacrylate separates in well-formed crystals. From these, by the addition of hydrochloric acid, we prepared the acid which, when recrystallized from hot water and dried over sulphuric acid, gave the following results:—

I. 0.2037 grm. of the substance gave on combustion 0.3307 grm. CO_2 and 0.0553 grm. H_2O.

II. 0.2027 grm. of the substance gave 0.1577 grm. AgBr.
III. 0.2238 grm. of the substance gave 0.1739 grm. AgBr.

	Calculated for $C_3H_2(OC_6H_5)BrO_2$.	Found. I.	II.	III.
C	44.44	44.27		
H	2.88	3.02		
Br	32.93		33.11	33.07

Phenoxybromacrylic acid crystallizes from hot water in long silky needles, which melt at 138°. It is almost insoluble in cold water, and is somewhat sparingly soluble even in boiling water. In ether or alcohol it is very soluble; in chloroform or benzol it dissolves on warming, and crystallizes as these solutions cool. Carbonic disulphide dissolves it with more difficulty.

Potassic Phenoxybromacrylate. $KC_3H(OC_6H_5)BrO_2$. On cooling the hot solution of potassic mucophenoxybromate in potassic hydrate, potassic phenoxybromacrylate separates in well-formed rhombic plates, which may be recrystallized from hot water, although they are quite soluble even in cold water. The air-dried salt proved to be anhydrous.

I. 0.5073 grm. of the air-dried salt gave on ignition with H_2SO_4 0.1588 grm. K_2SO_4.
II. 0.5077 grm. of the air-dried salt gave on ignition with H_2SO_4 0.1572 grm. K_2SO_4.

	Calculated for $KC_3H(OC_6H_5)BrO_2$.	Found. I.	II.
K	13.91	14.06	13.90

Baric Phenoxybromacrylate. $Ba(C_3H(OC_6H_5)BrO_2)_2.5H_2O$. On neutralizing a boiling solution of the acid with baric carbonate, and evaporating on the water-bath, the barium salt was obtained in the form of radiating prisms, which were permanent in the air and hardly lost in weight over sulphuric acid. It was freely soluble in cold water. The air-dried salt gave on analysis: —

I. 1.2120 grm. of the air-dried salt lost at 110° 0.1535 grm. H_2O.
II. 1.0468 grm. of the air-dried salt lost at 110° 0.1345 grm. H_2O.
III. 0.6687 grm. of the air-dried salt lost at 110° 0.0855 grm. H_2O.

	Calculated for $Ba(C_3H(OC_6H_5)BrO_2)_2.5H_2O$.	Found. I.	II.	III.
H_2O	12.66	12.67	12.85	12.78

0.5017 grm. of the salt dried at 110° gave on ignition with H_2SO_4 0.1873 grm. $BaSO_4$.

	Calculated for $Ba(C_3H(OC_6H_5)BrO_2)_2$.	Found.
Ba	22.06	21.95

Calcic Phenoxybromacrylate. $Ca(C_3H(OC_6H_5)BrO_2)_2.5H_2O$. The calcium salt was prepared from the acid by neutralizing its aqueous solution with calcic carbonate. It was readily soluble in water, and crystallized on cooling its concentrated solution in clustered needles, which were permanent in the air or over sulphuric acid.

I. 0.9361 grm. of the air-dried salt lost at 100–105° 0.1381 grm. H_2O.
II. 0.7563 grm. of the air-dried salt lost at 100–105° 0.1122 grm. H_2O.

	Calculated for $Ca(C_3H(OC_6H_5)BrO_2)_2.5H_2O$.	Found. I.	Found. II.
H_2O	14.66	14.75	14.84

0.5046 grm. of the salt dried at 100–105° gave on ignition with H_2SO_4 0.1310 gr. $CaSO_4$.

	Calculated for $Ca(C_3H(OC_6H_5)BrO_2)_2$.	Found.
Ca	7.64	7.64

Argentic Phenoxybromacrylate. $AgC_3H(OC_6H_5)BrO_2$. The silver salt may be precipitated by the addition of argentic nitrate to a hot aqueous solution of the acid. It crystallizes in needles which may be recrystallized without decomposition from boiling water. When dried over sulphuric acid, the salt gave the following results: —

I. 0.4464 grm. of the salt gave on precipitation with HBr. 0.2391 grm. AgBr.
II. 0.4240 grm. of the salt gave on precipitation with HBr 0.2268 grm. AgBr.

	Calculated for $AgC_3H(OC_6H_5)BrO_2$.	Found. I.	Found. II.
Ag	30.85	30.77	30.72

Phenoxybromacrylic acid is therefore one of the products formed from mucophenoxybromic acid by the action of potassic hydrate. The mother liquors from which the potassic phenoxybromacrylate had crystallized yielded on acidification with dilute sulphuric acid and distillation an acid distillate, which gave with ferric chloride and bromine water reactions showing the presence of small quantities of phenol. When neutralized with calcic carbonate and evaporated, it left calcic

formiate, which was identified by its characteristic behavior with argentic nitrate and mercuric chloride. The decomposition of mucophenoxybromic acid by potassic hydrate may therefore be expressed by the reaction: —

$$C_4H_2(OC_6H_5)BrO_3 + H_2O = C_3H_2(OC_6H_5)BrO_2 + CH_2O_2.$$

While dibromacrylic acid passes readily into brompropiolic and malonic acids in an alkaline solution, phenoxybromacrylic acid is apparently unaltered by aqueous potassic hydrate. Even after long boiling in a concentrated solution (2 : 1) no potassic bromide is formed.

Phenoxybrommaleic Acid.

On warming a solution of mucophenoxybromic acid with argentic oxide, metallic silver is readily formed. If the solution is then heated to boiling, and the silver precipitated by hydrochloric acid, the filtered solution deposits on cooling phenoxybrommaleic acid in the form of fine felted needles. Their melting-point, when taken in the ordinary way, we found to be 103–104°; but when slowly heated, the melting-point was materially lowered, probably through the formation of the anhydride. From the analysis of substance which had been dried over sulphuric acid, it would seem that here also a certain amount of the anhydride was formed, and that in this respect its behavior is perfectly analogous to that of dibrommaleic acid which is partially converted into anhydride by drying, as one of us has shown: * —

I. 0.1213 grm. of substance dried over H_2SO_4 gave on combustion 0.1935 grm. CO_2 and 0.0245 grm. H_2O.

II. 0.2204 grm. of substance dried over H_2SO_4 gave 0.1494 grm. AgBr.

	Calculated for $C_4H_2(OC_6H_5)BrO_4$.	Calculated for $C_4(O_2C_6H_5)BrO_3$.	Found. I.	Found. II.
C	41.81	44.61	43.51	
H	2.44	1.86	2.25	
Br	27.87	29.74		28.85

Ratio of carbon to bromine atoms as found = 10 : 0.995.

Argentic Phenoxybrommaleate. $Ag_2C_4(OC_6H_5)BrO_4$. By the addition of argentic nitrate to an aqueous solution of the acid, the silver salt is precipitated in the form of clustered rhombic plates, which may

* These Proceedings, Vol. XVI. (N. S. VIII.) p. 178.

be recrystallized from boiling water without decomposition. The dry salt is decomposed suddenly by heat, but without detonation.

I. 0.3922 grm. of the salt dried over H_2SO_4 gave on precipitation with HBr 0.2928 grm. AgBr.

II. 0.2903 grm. of the salt dried over H_2SO_4 gave on precipitation with HBr 0.2168 grm. AgBr.

	Calculated for $Ag_2C_4(OC_6H_5)BrO_4$.	Found. I.	Found. II.
Ag	43.12	42.88	42.90

The relation which mucophenoxybromic acid bears to mucobromic is sufficiently shown by its conversion into phenoxybromacrylic and phenoxybrommaleic acids under conditions identical with those necessary to the formation of dibromacrylic and dibrommaleic acids from mucobromic. Furthermore, it is evident that the extreme stability of the phenoxybromacrylic acid in alkaline solution shows that the phenoxyl group has taken the place of the bromine atom which is so readily removed from the corresponding dibromacrylic acid in the formation of brompropiolic acid.

If mucobromic acid be written,

$$\begin{array}{l} \mathrm{CHO} \\ \mid \\ \mathrm{CBr} \\ \parallel \\ \mathrm{CBr} \\ \mid \\ \mathrm{COOH} \end{array}$$

it follows that mucophenoxybromic acid has the form, —

$$\begin{array}{l} \mathrm{CHO} \\ \mid \\ \mathrm{CBr} \\ \parallel \\ \mathrm{C-O.C_6H_5} \\ \mid \\ \mathrm{COOH} \end{array}$$

and the acrylic acid derived from it has the form, —

$$\begin{array}{l} \mathrm{CHBr} \\ \parallel \\ \mathrm{C-O.C_6H_5} \\ \mid \\ \mathrm{COOH.} \end{array}$$

X.

SIR WILLIAM HERSCHEL'S OBSERVATIONS OF VARIABLE STARS.

By Edward C. Pickering.

Presented January 9, 1884.

The discovery last summer of two additional catalogues of the Light of the Stars by Sir William Herschel has been announced elsewhere. At the same time a Journal was found, which gives the dates of observation for the individual comparisons contained in the six catalogues. The suggestion was made by Mr. Chandler, that the observations of variable stars contained in these catalogues would thus be rendered of value. The observations contained in Table I. were kindly forwarded by Lieut. Col. Herschel, who has taken much trouble in furnishing me with all the material available for the following discussion. The successive columns of Table I. give a current number, the number of the catalogue of Herschel in which the star is contained, the usual designation of the star, and its Flamsteed number. The next columns give the date, the observation, and the resulting magnitude. The latter is derived from the photometric observations made in 1879–82 at Harvard College Observatory with the meridian photometer, and will appear in the Annals of the Observatory, Volume XIV. The values assumed for the intervals employed by Herschel are obtained from a discussion of all his catalogues, and will appear in the same volume; they are 0.1 for a period, 0.2 for a comma, and 0.4 for a dash.

The scale employed may be defined as that in which a magnitude corresponds to the ratio whose logarithm is four tenths, and which coincides with the scale of Argelander for the magnitude 5. It is best illustrated by the statement that the magnitudes 3, 4, 5, and 6 on the scales of the Uranometria Nova, Heis, and the Durchmusterung would be expressed by 3.1, 4.2, 5.0, and 5.8 on the photometric scale.

TABLE I.

No.	Cat.	Name.	Fl.	Date.	Comparison.	Magn.
1	I.	η Aquilæ	55	1795, July 19	65, 30, 55. 60	3.8
2		"		" "	60. 55	4.1
3		"		" "	55 — 41 — 38. 44	3.9
4		"		1795, July 25	41, 55	4.5
5	I.	g Herculis	30	1795, May 23	1, 30	4.7
6		"		1795, May 25	30 — 25	5.1
7		"		" "	11. 35 — 6, 30	4.9
8		"		" "	6, 52, 30	5.2
9		"		" "	52, 42. 30, 34	5.6
10		"		1795, Sept. 20	30. 1	4.4
11		"		" "	30 —, 25	4.9
12	I.	u Herculis	68	1795, May 22	71. 68, 72	5.2
13		"		" "	68, 90, 72	5.1
14		"		1795, Aug. 18	68, 59, 61	5.1
15		"		" "	60 — 68	5.8
16	II.	o Ceti	68	1779, Nov. 30	$\beta > o > \alpha$	2.4
17		"		1798, Feb. 18	68. 82	4.0
18	II.	η Geminorum	7	1795, Mar. 29	$\mu - \eta - \xi''$	3.3
19		"		" "	$\mu - \epsilon - \eta$	3.6
20		"		1795, Nov. 7	27 ¦ 13, 7 — 31	3.2
21		"		1796, Feb. 1	13 ; 7	3.3
22		"		" "	13. 7 —, 31	3.1
23		"		1796, Nov. 30	13 —, 123 Tauri, 7	3.2
24	II.	ζ Geminorum	43	1795, Nov. 7	55. 77, 84 — 48	4.1
25	III.	δ Cephei	27	1796, Nov. 5	32, 27	3.8
26	IV.	β Lyræ	10	1782, May 12		—
27		"		1795, May 5		—
28		"		1795, Sept. 15	14 —, 10	3.8
29	IV.	R Lyræ	13	1796, Aug. 28	12. 13	4.5
30		"		" "	21. 20, 13	4.7
31	IV.	ρ Persei	25	1795, Aug. 21	28, 25 — 41, 46	3.4
32		"		1796, Sept. 7	45 — — 39 — 25	3.6
33	IV.	λ Tauri	35	1796, Jan. 1	1 — 2, 35. 38	4.0
34		"		1796, Nov. 30	123 —, 35	3.6
35	V.	X Sagittarii	3	1795, Sept. 15	2, 3	—
36	VI.	δ Libræ		1795, May 11	37, 31. 35, 44. 19. 48. 45. 6	5.2
37		"		1795, May 18	37, 31, 19	5.4
38		"		" "	7, 19	5.6
39		"		1797, May 22	19. 18	5.9

The following remarks appear in the original record: —

No. 16. "*o Ceti* is less than β and larger than α. See p. 26."

No. 22. "Seems to be larger than it has been."

No. 26. "To the n-eye γ much larger than β. (Mem. This star is changeable, and was then at its minimum.)"

No. 27. "β *Lyræ* much less than γ, $10^h\ 45^m$ com. time."

No. 28. "10 seems to be at its minimum."

The variations of several of these stars are irregular, or at least the law governing them is not yet known. It is evident that these obser-

vations will hereafter form a most valuable test of the correctness of any assumed law, since in many cases they precede by more than half a century any other observations of these stars of the same degree of precision. This is shown in Table II., which gives in successive columns the name of the star, the number of observations contained in Table I., the year in which the variability was discovered, and the number of years by which this followed the observations of Herschel. A dash is inserted when the discovery preceded the observations. In these cases the observations of Herschel have less value, since we have contemporaneous or antecedent observations which serve to determine the nature of the changes. The last three columns give the period in days, and the magnitude at maximum and minimum, according to the catalogue of Professor Schönfeld.*

TABLE II.

Name of Star.	No. Obs.	Discov.	Years.	Period.	Variation. Schönfeld.	
η Aquilæ	4	1784	—	7.2	3.5	4.7
g Herculis	8	1857	62	irr.	5	6.2
u Herculis	5	1869	74	irr.	4.6	5.4
o Ceti	3	1596	—	331.3	1.7–5.0	8–9
η Geminorum	9	1865	70	229.1	3.2	3.7–4.2
ζ Geminorum	1	1844	49	10.2	3.7	4.5
δ Cephei	1	1784	—	5.3	3.7	4.9
β Lyræ	3	1784	—	12.8	3.4	4.5
R Lyræ	2	1856	60	46.0	4.3	4.6
ρ Persei	3	1854	59	irr.	3.4	4.2
λ Tauri	3	1848	52	3.9	3.4	4.2
X Sagittarii	1	1866	71	7.0	4	6
δ Libræ	5	1859	64	2.3	4.9	6.1

The individual stars will now be considered in turn, so far as the material exists for a more complete reduction than is given in Table I.

η Aquilæ. — The variation in light of this star has been discussed by Argelander.† A light curve is given by which the brightness at any time may be expressed in terms of an arbitrary scale of grades. This scale is defined by expressing in grades the light of the comparison stars used in determining the changes in brightness of the variable. Points have been constructed for each of these stars, with grades as abscissas, and the photometric magnitudes as ordinates. A straight

* Zweiter Catalog von veränderlichen Sternen. Mannheim, 1875.

† Astron. Nach., xix. 399.

line drawn nearly through these points serves to convert the scale of grades into photometric magnitudes, or into actual light ratios. From this we may conclude that the maximum and minimum light of the variable expressed in photometric magnitudes is 3.7 and 4.5. The range is accordingly less than that ordinarily given, but this is partly due to the difference in the scales. The observations of Herschel expressed in grades equal 9.6, 6.1, 8.5, and 1.0. The first three of these correspond to periods of $1^d\ 19^h$, $1^d\ 4^h$, and $1^d\ 14^h$, after a minimum, if the light of the star was increasing, or to $3^d\ 4^h$, $5^d\ 6^h$, and $3^d\ 14^h$, if the light was diminishing. The other observation, No. 4, which was made six days later, on July 25, serves to decide between these two hypotheses. The light was then sensibly that of a minimum at 1.2 grades. As the period of the star is about $7^d\ 4^h$, a minimum about a day preceding the observations 1, 2, and 3 would also be indicated by observation 4. This would agree with the hypothesis that the light was increasing on July 19, but would controvert the view that it was diminishing.

The time of the observations is defined only by the limits of twilight, which in the latitude of Slough would extend to within about two hours of midnight in July. The star would culminate near midnight, and could be easily observed as long as darkness lasted. The times of observation may therefore be written, 1795, July $19^d\ 12^h \pm 2^h$, and 1795, July $25^d\ 12^h \pm 2^h$. The mean of the three results on July 19 would give an interval from the minimum of $1^d\ 12^h$, or would place the preceding minimum at 1795, July $18^d\ 0^h$, with an uncertainty of several hours, since a small error in the light corresponds to a large deviation in the time of minimum. The elements of Argelander indicate a minimum 1795, July $18^d\ 19^h\ 42^m$ Paris M. T.

g Herculis. — The variations in light of this star are irregular, or the law governing them has not yet been discovered. Should this law ever be determined, these observations may have great value, since they anticipate by sixty-two years the first observations of equal accuracy previously known. Probably the variations are so slow that the hour at which the observations were made will not be needed.

u Herculis. — The same remark applies to this star as to the preceding. The observations are accordant, and anticipate other similar observations by seventy-four years.

o Ceti. — Some other observations by Sir William Herschel are given by Argelander.* As this star had been observed for many years previously, these observations are not of especial importance.

* Bonn Beob., vii. 329.

η Geminorum. — These observations precede by seventy years those taken elsewhere. They will therefore have great value in determining the period when the nature of the variations is more accurately established. The small change in light, however, makes the result derived from any small number of observations somewhat doubtful.

ζ Geminorum. — A comparison of the results obtained by Argelander * with the photometric measures gives the variation in light of this star from 3.6 to 4.2. It was therefore apparently observed by Herschel near its minimum. The light curve indicates that the observation preceded or followed a minimum by about nineteen hours, but the change in brightness during this time is much less than the uncertainty of the observation. The ephemeris of Schönfeld indicates a minimum for Ep. —2434 at 1795, Nov. 8^d $5^h.6$, which does not differ from the time of observation by as much as the uncertainty of the comparison.

δ Cephei. — According to the curve of Argelander,† this star has the magnitudes of 3.5 and 4.3 at maximum and minimum. The observation of Herschel would correspond to 8.0 grades. This indicates a minimum preceding it by 1^d 2^h or 2^d 20^h, according as the light was increasing or decreasing. The star is above the horizon nearly all night, hence the time of observation is fixed only by the limits of twilight. We may therefore call the time of observation, 1796, Nov. 5^d $12^h \pm 6^h$. The elements of Schönfield give for Ep. —2987 a minimum at 1796, Nov. 4^d 7^h 24^m, which agrees as well as could be desired with the observation. As in the case of *η Aquilæ*, the observations of contemporaneous observers fix the period of this star so accurately that a correction based upon a small number of observations does not seem justifiable.

β Lyræ. — The variations of this star have been so thoroughly determined by other observers that these observations cannot add much to our knowledge of the subject. Only one observation, No. 28 of Table I., is sufficiently precise to be of value, and the interval here employed —, is too large to be estimated with accuracy. This observation has therefore not been reduced.

R *Lyræ.* — The variations of this star are so small that it is doubtful if the observations of Herschel can be utilized.

ρ Persei. — The same remark may be applied to this star as to *g Herculis.*

λ Tauri. — This star belongs to the Algol class. The maximum

* Bonn Beob., vii. 389. † Astron. Nach., xix. 395.

brightness as given in the photometric catalogue is 3.6. The agreement of the observation No. 34 is probably accidental, since the large interval —, cannot be estimated with accuracy. As far as it goes, however, it indicates that the star was at its full brightness. The other observation, No. 33, indicates a diminution of light, or that the star was near a minimum. The law of variation of light is not known, but probably the change in magnitude amounts to about 0.8. The star retains its full brightness except for about two hours before and after each minimum. We may accordingly assume that a minimum preceded or followed the observation No. 33 by about one hour. On this day the sun set at about $3^h\ 47^m$ and λ *Tauri* set at $16^h\ 10^m$. Allowing for twilight, we may accordingly assume 1796, Jan. $1^d\ 10^h \pm 5^h$ for the time of observation. For the other date we obtain, in like manner, 1796, Nov. $30^d\ 11^h \pm 6^h$. The ephemeris of Schönfeld, applying the equation of light, gives 1795, Dec. $31^d\ 22^h.6$, for Ep. —6500. A correction to the ephemeris of $-11^h.5$ is thus indicated. This exceeds the possible error in the time, added to the probable error in magnitude. In other words, if the star was really below its full brightness, the minimum must have occurred several hours after the computed time. In like manner, we obtain 1796, Dec. $1^d\ 22^h.3$ for Ep. —6485, or the nearest minimum does not occur until 35 hours after the observation No. 34. Accordingly, as the observation indicated, the star should have had its full brightness. The first minimum previously known of this star occurred on Dec. 6, 1848. If it were possible to determine the hour of Herschel's observation, the mean period of this star would be determined with great precision. An uncertainty of one hour would correspond to about half a second in a single period.

X *Sagittarii.*—This star varies in light from about 4.5 to 5.8 in a period of a little over seven days. The only comparison made by Herschel places this star a little fainter than 2 *Sagittarii*. The latter star is commonly placed in Ophiuchus,—in fact, it is nearly in line with 52 and 58 *Ophiuchi*, and between them. Its magnitude, according to the Uranometria Argentina is 6.8, which corresponds to 6.6 on the photometric scale. This would make the variable much too faint, even if at its minimum. It is also strange that Herschel should have employed a star at so great a distance (about 8°), when he might have taken others about equally faint and nearer. The hypothesis that 2 *Sagittarii* was much brighter then than now, is negatived by the fact that Herschel compared it with 52 *Ophiuchi*, and found it only slightly brighter. The magnitude of this star in the Uranometria

Argentina is 6.5, corresponding to a photometric magnitude of 6.3. This value, although reducing the discrepancy, would still make the variable 6.5, which is 0.7 fainter than its light at minimum. This comparison is not given in the catalogue of Herschel, and accordingly is not checked by appearing under both 2 and 3 *Sagittarii*.

The southern declination of the star restricts the time of observation within narrow limits. The star sets at 9^h, and twilight would not be over until about 7^h. Accordingly, the time of observation would be 1795, Sept. $15^d\ 8^h \pm 1^h$. The elements of Schönfeld* give a minimum at 1795, Sept. $15^d\ 16^h$, for Ep. —3902. The period of Schmidt,† on the other hand, gives 1795, Sept. $13^d\ 22^h$. If, then, the star was really at its minimum when observed by Herschel, this observation determines a correction to the period with great certainty.

δ *Libræ*. — The observations of this star are so important that they require a more detailed discussion. The law of variation of the light has been determined by Professor Schönfeld.‡ Table III. gives the names of the various comparison stars, the letters by which they are designated by Professor Schönfeld, and the brightness in grades that he assigned to them. The next columns give the light according to the photometric measures made at this Observatory, and according to the Uranometria Argentina. The grades are reduced to magnitudes, as described on page 271, according to each of the scales. The results found by subtracting the magnitudes derived from the grades from that given in the two catalogues are given in the last two columns.

TABLE III.

Names.	Desig.	Grades.	H. P.	U. A.	H. P.	U. A.
37 Libræ	*f*	15.2	4.9	5.5	—2	—2
ε Libræ	*e*	12.5	5.2	5.5	—2	0
15 Hev.	*d*	8.5	5.0	5.6	+3	+3
178 Bode	*c*	3.5	5.6	6.2	0	+1
B. A. C. 4945	*b*	0.0	—	6.6	—	0

The light of the variable at maximum and minimum equals 13.0 and 2.0 grades respectively. This corresponds to a variation from 4.9 to 5.8 on the photometric scale, and from 5.5 to 6.4 on the scale of the Uranometria Argentina.

The observations of Sir William Herschel are compared in Table IV.

* Zweiter Catalog.

† Astron. Nach., lxxxvii. 109.

‡ Astron. Nach., lxxiv. 342.

The successive columns give the Flamsteed numbers, the photometric magnitudes, and the magnitudes according to Sir William Herschel. These have been derived from a discussion of all six catalogues of Herschel. They have a special value for the present purpose, since they indicate the brightness of these stars at the time the observations now under consideration were made. The fourth column gives the magnitude according to the Uranometria Argentina. The magnitude of 19, δ *Libræ*, according to each of these scales is inserted in brackets.

TABLE IV.

Fl.	H. P.	W. H.	U. A.	Fl.	H. P.	W. H.	U. A.
37	4.9	5.1	5.5	37	4.9	5.1	5.5
31	5.2	5.0	5.5	31	5.2	5.0	5.5
35	5.4	5.9	5.8	19	[5.4]	[5.2]	[5.7]
44	5.5	5.4	5.9	7	5.4	5.0	5.7
19	[5.2]	[5.1]	[5.7]	19	[5.6]	[5.2]	[5.9]
43	5.0	4.8	5.5	19	—	[5.9]	[6.2]
45	5.0	5.2	5.5	18	—	6.0	6.8

The scale of the Uranometria Argentina differs two or three tenths of a magnitude from that of the photometer for stars of the fifth and sixth magnitude. For the stars used in this comparison the difference amounts to four tenths of a magnitude. Applying this correction, the results become more readily comparable without affecting the conclusions derived from them. In Table V. the brightness of δ at the time of the various observations, and at maximum and minimum, as stated in the first column, is compared. The following columns give the magnitude derived in Table IV. from the three authorities, after applying a correction of four tenths of a magnitude to the Uranometria Argentina. The last column gives a mean value which may be employed, since all the observations have been reduced to the same scale.

TABLE V.

	H. P.	W. H.	U. A.	Mean.
1795, May 11	5.2	5.1	5.3	5.2
1795, May 18	5.4	5.2	5.3	5.3
" "	5.6	5.2	5.5	5.4
1797, May 22	—	5.9	5.8	5.8
Maximum	4.9	—	5.1	5.0
Minimum	5.8	—	6.0	5.9

A minimum is clearly indicated in 1797, May 22, and the star seems to have been below its maximum brightness on the other nights also. Converting the magnitudes into grades, and comparing with the light curve of Professor Schönfeld, we may infer that on 1795, May 11, the observation was made $4^h.7$ before, or $5^h.2$ after, a minimum. The observations of 1795, May 18, in like manner, indicate that a minimum would follow in $3^h.4$, or had passed $3^h.8$. The observation of 1797, May 22, indicates a brightness that does not differ sensibly from that at minimum. The star changes in brightness by about a tenth of a magnitude within an hour of minimum.

The hours within which the observations must have been made are limited by the twilight, which would, for observations of such faint stars, be appreciable within two hours of midnight. The comparison stars 43 and 44 *Libræ* would be above the horizon from $8^h.0$ to $16^h.4$. Their altitudes would exceed 10° from $9^h.2$ to $15^h.2$.

The period of δ *Libræ* is $2^d\ 7^h\ 51^m\ 20^s = 2^d.3273148$. Accordingly, if a minimum occurred near midnight on 1797, May 22, others would have occurred on the afternoons of 1795, May 11, and 1795, May 18. We may therefore assume that the observations of 1795 were made after, and not before minima. Subtracting from the time 1795, May $11^d\ 12^h$, the interval $5^h.2$, adding $0^h.2$ for the difference in longitude of Slough and Paris, and adding $0^h.1$ for the equation of light, we obtain 1795, May $11^d\ 7^h.1$, for the Paris heliocentric time of minimum. The times of minima indicated for the other observations are given with this in the first column of Table VI. The second column gives the ephemeris time for the epoch given in the third column. The last column gives the observed minus the computed times of minima.

TABLE VI.

Observed.	Computed.	Epoch.	O. — C.
d. h.	d. h.		h.
1795, May 11 7.1	May 11 11.9	—10980	—4.8
1795, May 18 8.5	May 18 11.5	—10977	—3.0
1797, May 22 12.3	May 22 21.8	—10661	—9.5

The mean of these results indicates a correction of six hours to the ephemeris, or of seven hours, if we assign somewhat greater weight to the last observation. A most fortunate coincidence brought all the observations so near minimum that the star had in each case less than

its normal light. Observations of the maximum light would have had comparatively little value.

The times of minima on May 11 and May 18, 1795, are somewhat uncertain, since the assumed light of the comparison stars may be in error. All the stars with which δ *Libræ* was compared have accordingly been arranged in sequences by Mr. Chandler, since the above reduction has been made. The details of these observations will be published elsewhere, but they give a correction for the minima of May 11 and May 18 of —2.3 and —2.5, instead of —4.8 and —3.0 hours.

XI.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

By Charles F. Mabery.

Presented March 12, 1884.

No. I.—ON β-BROMTETRACHLORPROPIONIC ACID.

With the hope of establishing the structure of certain bromdichloracrylic acids which I have at present under examination, I endeavored to prepare an acid of the same empirical composition by the addition of a molecule of chlorine to brompropiolic acid.*

In studying the relations of these substances toward each other under different conditions, it was found that the action of chlorine upon the melted acid was so violent that frequently it resulted in an explosion. Even at ordinary temperatures a gaseous product was freely evolved, with a disagreeable odor resembling that of phosgene.

As previous experiments had shown, in a chloroform solution of the acid the action of chlorine could easily be controlled; in fact, for some time it could not be determined whether the addition had begun, since evaporation of the chloroform left only a pasty mass which refused to crystallize. Finally, after continuing the action for several hours, a crust began to form above the solution, and soon the greater part of a crystalline addition product was deposited.

This substance proved to be sparingly soluble in cold carbonic disulphide and chloroform, more soluble in hot, and after purification it melted with decomposition at 225°. The percentage composition calculated from the results of analysis corresponds to that of bromtetrachlorpropionic acid.

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* In a former paper (Mabery and Robinson, these Proceedings, Vol. XVIII. p. 45) it was stated that a bromdichloracrylic acid could be prepared by passing chlorine through a chloroform solution of brompropiolic acid cooled to 0°. This statement was evidently made upon insufficient evidence, since all subsequent attempts to obtain the same result have proved unsuccessful.

I. 0.2000 grm. of the substance gave 0.5235 grm. AgBr + AgCl.
II. 0.5874 grm. of the substance gave 0.2732 grm. CO_2 and 0.0268 grm. H_2O.
III. 0.5385 grm. of the substance gave 0.2330 grm. CO_2.*

	Calculated for $C_3HCl_4BrO_2$.	Found. I.	II.	III.
C	12.37		12.67	11.82
H	.34		.51	
4 Cl + Br.	76.30	76.26		

The salts of this acid are extremely unstable. It dissolves readily in sodic or potassic carbonate, or in ammonic hydrate, and is precipitated by hydrochloric acid; yet the corresponding salts could not be prepared sufficiently pure for analysis. When treated with baric carbonate, the acid dissolves with the formation at first of a clear solution; but soon the latter becomes turbid from the separation of an oil, which continues until the decomposition of the salt is complete. Although this oil was not submitted to analysis, it is probably tetrachlorethylen. The silver salt which is formed when argentic nitrate is brought in contact with the acid, soon changes color, even in the dark, and all attempts to prepare it in a form suitable for analysis were unsuccessful.

Unless a molecular rearrangement takes place during the addition of chlorine, which does not seem at all probable, the structure of this acid must be represented by the formula: —

$$\begin{array}{l} CBrCl_2 \\ | \\ CCl_2 \\ | \\ COOH. \end{array}$$

Many variations of the method of preparation above described have been tried in order, if possible, to limit the addition of chlorine to the formation of a bromdichloracrylic acid. The appearance of the product and its behavior toward solvents at different stages of the chlorination would seem to indicate that each molecule of brompropiolic acid absorbed two molecules of chlorine, thereby forming a mixture of bromtetrachlorpropionic acid and unaltered brompropiolic. This would, of course, preclude the possibility of obtaining by the addition of chlorine the corresponding substituted acrylic acid.

* By accident the water in this combustion was lost.

No. II.—ON α- AND β-CHLORDIBROMACRYLIC ACIDS.*

By Charles F. Mabery and Rachel Lloyd.

α-Chlordibromacrylic Acid.

In a former paper by F. C. Robinson and one of us,† a brief account was given of certain experiments in which we had tried to obtain an addition product of brompropiolic acid with chlorine monobromide. Although the results then obtained were rather unsatisfactory, it seemed possible nevertheless to prepare the addition product in a state of purity, and this became especially desirable when it was found that an acid of the same empirical composition could be formed from chlortribrompropionic acid.

In resuming the study of this reaction, it was evidently necessary to secure at the outset a combination of the halogens containing no free bromine, inasmuch as previous results had shown that a small percentage even of tribromacrylic acid could not be removed from the product by crystallization. On the other hand, an excess of chlorine was not objectionable since it had been found that this substance in the free state united much less readily with brompropiolic acid than when combined with bromine. The chlorine monobromide used to form this addition product was therefore made by saturating bromine at 0° with chlorine; and to insure complete saturation the resulting product was dissolved in chloroform and this solution saturated at 0°. Brompropiolic acid was then added gradually, taking care to keep the solution cold and the chlorine monobromide in excess. Chemical action immediately ensued, and the formation of the addition product was complete after standing half an hour. Evaporation of the chloroform left a solid residue, which was easily purified by crystallization from hot water.

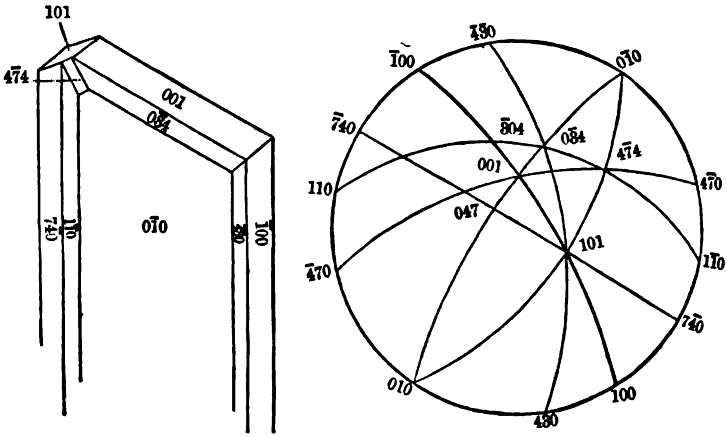
This acid is sparingly soluble in cold, very soluble in hot water, more soluble in hot than in cold carbonic disulphide, and very soluble in chloroform. Its melting point is 104°. By slow evaporation it separates from a solution in carbonic disulphide in triclinic prisms. These crystals have been submitted to careful study by

* The results described in papers II., III., and IV. were obtained under my direction in the summer course of instruction in chemistry for 1883.—C. F. M.

† These Proceedings, Vol. XVIII. p. 41.

Mr. Oliver W. Huntington,* to whom we are indebted for the following results: —

CRYSTALLINE FORM OF α-CHLORDIBROMACRYLIC ACID.



Triclinic System.

Forms {100}, {010}, {001}, {101}, $\{1\bar{1}0\}$, {430}, $\{0\bar{3}4\}$, $\{\bar{3}04\}$, $\{7\bar{4}0\}$, $\{\bar{4}70\}$, $\{4\bar{7}4\}$, {047} ?

From the fundamental angles the following values were calculated: —

X on Y 104° 43′, Y on Z 71° 6, X on Z 71° 10;

$a : b : c = 0.7981 : 1 : 0.7207.$

Angles between Normals.

	Observed.		Calculated.
010 on 100	66° 23′	Fundamental angles.	
100 " 001	116° 17′	Fundamental angles.	
010 " 001	116° 20′	Fundamental angles.	
100 " 101	63° 50′	Fundamental angles.	
100 " $1\bar{1}0$	47° 5′	Fundamental angles.	
100 " 430			23° 52′
100 " $7\bar{4}0$	27°		27° 5′
010 " $\bar{4}70$	42°.26′		42° 36′
$00\bar{1}$ " $0\bar{3}4$	21°		21°

In the paper above referred to Mr. Huntington makes the following

* These Proceedings, Vol. XVIII p. 282.

remarks concerning the planes $\{430\}$, $\{0\bar{3}4\}$, $\{\bar{3}04\}$, $\{7\bar{4}0\}$, $\{\bar{4}70\}$, $(4\bar{7}4)$, $\{047\}$?: "These symbols were for the most part deduced from the zone intersections, and the indices could only in a few cases be verified by angular measurements. The faces of the vertical prism especially were very irregular, in consequence of the alternations caused by parallel grouping, so common with artificial crystals; and although the relative position of the fundamental planes could be accurately fixed, the symbols of the intermediate planes must be regarded as doubtful; these planes were seldom seen, and only in the vertical zone. The symbols given on the projection were obtained by finding the intersection with the vertical zone of other zones never well defined on the same crystal, and it can only be claimed that the approximate angular measurements on the vertical zone were compatible with the indices given above."

The composition of the purified acid was shown by analysis: —

I. 0.2254 grm. of the substance gave 0.4435 grm. AgCl + AgBr.
II. 0.2046 grm. of the substance gave 0.3980 grm. AgCl + AgBr.
III. 0.8187 grm. of the substance gave 0.3920 grm. CO_2 and 0.0273 grm. H_2O.

	Calculated for $C_3HCl_2BrO_2$.	Found. I.	II.	III.
2 Cl + Br	73.91	74.03	73.19	
C	13.56			13.05
H	.38			.37

In determining the solubility of this acid in cold water according to the method of V. Meyer, a saturated solution was neutralized with baric carbonate, and the barium determined in the filtered solution by precipitation with sulphuric acid.

I. 11.0890 grm. of a solution saturated at 20° gave 0.2344 grm. $BaSO_4$.
II. 1.6299 grm. of a solution saturated at 20° gave 0.0379 grm. $BaSO_4$.

From these results the following percentages were calculated: —

I.	II.
5.18	5.68

The barium, calcium, potassium, and silver salts of this acid were prepared and analyzed.

Baric a-Chlordibromacrylate, $Ba(C_3ClBr_2O_2)_2 . 3\,H_2O$. — On saturating an aqueous solution of the acid with baric carbonate a neutral

solution was obtained, from which, by evaporation, the barium salt separated in elongated flat prisms with oblique terminations. This salt is much less soluble in cold than in hot water. The crystals which separated from a hot solution were first dried to a constant weight in the air, then heated to 80°.

0.9545 grm. of the air-dried salt lost 0.0712 grm. H_2O at 80°.
0.8790 grm. of the anhydrous salt gave 0.3083 grm. $BaSO_4$.

	Calculated for $Ba(C_3ClBr_2O_2)_2 . 3 H_2O$.	Found.
H_2O	7.46	7.52
	Calculated for $Ba(C_3ClBr_2O_2)_2$.	
Ba	20.63	20.62

The solubility of the barium salt in cold water was also determined.

I. 1.4307 grm. of a solution saturated at 20° gave 0.1190 grm. $BaSO_4$.
II. 2.5352 grm. of a solution saturated at 20° gave 0.2142 grm. $BaSO_4$.

These results correspond to the following percentages: —

I.	II.
20.46	20.70

Calcic a-Chlordibromacrylate, $Ca(C_3ClBr_2O_2)_2 . 2\frac{1}{2} H_2O$. — The calcium salt was prepared by neutralizing an aqueous solution of the acid with calcic carbonate. From the concentrated solution the salt separated in irregular branching needles, which lost two and one half molecules of crystal water at 80°, after drying to constant weight in the air.

I. 1.2644 grm. of the air-dried salt lost 0.1006 grm. H_2O at 80°.
II. 0.9273 grm. of the air-dried salt lost 0.0714 grm. H_2O at 80°.

	Calculated for $Ca(C_3ClBr_2O_2)_2 . 2\frac{1}{2} H_2O$.	Found. I.	Found. II.
H_2O	7.80	7.95	7.70

I. 0.8166 grm. of the anhydrous salt gave on ignition with H_2SO_4 0.2016 grm. $CaSO_4$.
II. 0.8328 grm. of the anhydrous salt gave 0.1835 grm. $CaSO_4$.

	Calculated for $Ca(C_3ClBr_2O_2)_2$.	Found. I.	Found. II.
Ca	7.05	7.26	6.47

Potassic a-Chlordibromacrylate, $KC_3ClBr_2O_2$? — A solution of the acid was carefully neutralized with potassic carbonate, evaporated to a

small volume on the water bath, and finally to dryness over sulphuric acid. It formed a deliquescent amorphous crust, in which the potassium was determined after drying at 80°.

1.0508 grm. of the salt dried at 80° gave 0.3124 grm. K_2SO_4.

	Calculated for $KC_3ClBr_2O_2$.	Found.
K	12.92	13.36

Argentic α-Chlordibromacrylate, $AgC_3ClBr_2O_2$. — The silver salt was prepared by the addition of argentic nitrate to an aqueous solution of the barium salt. It separated as a curdy precipitate, which could be recrystallized from hot water without perceptible decomposition. It crystallizes in rhombic plates, and is not affected by ordinary daylight.

0.4715 grm. of the salt gave 0.1799 grm. AgCl.

	Calculated for $AgC_3ClBr_2O_2$.	Found.
Ag	29.07	28.72

β-Chlordibromacrylic Acid.

The readiness with which chlortribrompropionic acid is decomposed by alkaline hydrates has already been described,* and chlordibromethylen was identified as one of the products when the decomposition was effected with the aid of heat in a strongly alkaline solution.

A more careful study of the conditions has shown that a halogen atom may be eliminated without severing the connection of the carbon atoms. If the solution is kept cold, and a calculated amount of the alkaline hydrate — by preference baric hydrate — is added slowly, it will retain its acid reaction until the change represented by the following equation is nearly complete:

$$2C_3ClBr_3O_2H_2 + 2BaO_2H_2 = Ba(C_3ClBr_2O_2)_2 + BaBr_2 + 4H_2O.$$

The solution must then be made slightly alkaline, and kept so for twenty-four hours. On acidifying with hydrochloric acid, the resulting chlordibromacrylic acid is partially precipitated as an oil, and the remainder may be extracted from the solution with ether.

The acid is purified by crystallization from hot water, in which it is far more soluble than in cold. It is very soluble in ether and alcohol, less soluble in carbonic disulphide and chloroform. By slow evaporation from a solution in carbonic disulphide it crystallizes in oblique prisms, which melt at 99°.

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* These Proceedings, Vol. XVIII. p. 45.

Several attempts were made by Mr. Huntington to determine the crystalline form of this acid in order to compare it with that of α-chlordibromacrylic acid. But unfortunately all the crystals we were able to obtain for that purpose gave very imperfect reflections, and Mr. Huntington was able to say only that in their general habit they resembled closely those he had already measured of the α-acid. A few planes gave fairly good reflections, and the angles thus measured were nearly the same as those of the α-acid.

	α-Chlordibromacrylic Acid.	β-Chlordibromacrylic Acid.	Calculated.
010 on 100	66° 23′	67°	
010 " $\bar{4}$70	42° 26′	44° 25′	
0$\bar{1}$0 " 7$\bar{4}$0		42° 26′	42° 36′

The composition of the purified acid was established by analysis.

I. 0.2472 grm. of the substance gave 0.4869 grm. AgCl + AgBr.
II. 0.2060 grm. of the substance gave 0.4016 grm. AgCl + AgBr.
III. 0.7566 grm. of the substance gave 0.3690 grm. CO_2 and 0.0325 grm. H_2O.
IV. 0.4714 grm. of the substance gave 0.2319 grm. CO_2 and 0.0227 grm. H_2O.

	Calculated for $C_3HClBr_2O_2$.	Found. I.	II.	III.	IV.
Cl + 2Br	73.91	74.09	73.33		
C	13.61			13.30	13.42
H	.38			.48	.54

The solubility of the acid was determined by the method of V. Meyer. After neutralization with baric carbonate the barium was precipitated from the filtered solution with sulphuric acid.

I. 7.1822 grm. of a solution saturated at 20° gave 0.0789 grm. $BaSO_4$.
II. 5.3623 grm. of a solution saturated at 20° gave 0.0548 grm. $BaSO_4$.

From these results the following percentages were calculated: —

I.	II.
2.69	2.50

A study of the salts of this acid developed important differences between them and the corresponding salts of α-chlordibromacrylic acid.

Baric β-Chlordibromacrylate, $Ba(C_3ClB_2O_2)_2 . 3 H_2O$. — A solution of the acid was heated with an excess of baric carbonate, filtered, and concentrated by evaporation. On cooling, the barium salt crystallized in oblique slender prisms, which were somewhat more soluble in cold water than the barium salt of the α-acid. After drying to a constant weight in the air the salt contained three molecules of crystal water, which were slowly given up over sulphuric acid, but more rapidly at 80°.

I. 0.7765 grm. of the air-dried salt lost 0.0565 grm. H_2O at 80°.
II. 1.0502 grm. of the air-dried salt lost 0.0782 grm. H_2O at 80°.
III. 0.7185 grm. of the anhydrous salt gave 0.2462 grm. $BaSO_4$.
IV. 0.5975 grm. of the anhydrous salt gave 0.2051 grm. $BaSO_4$.

	Calculated for $Ba(C_3ClBr_2O_2)_2 . 3 H_2O$.	Found. I.	II.
H_2O	7.52	7.27	7.45

	Calculated for $Ba(C_3ClBr_2O_2)_2$.	III.	IV.
Ba	20.63	20.15	20.18

In determining the solubility of the barium salt in cold water the following results were obtained: —

I. 1.5511 grm. of a solution saturated at 20° gave 0.1413 grm $BaSO_4$.
II. 1.8345 grm. of a solution saturated at 20° gave 0.1676 grm. $BaSO_4$.

The solubility of the salt in water at 20° is therefore shown by the following percentages: —

I.	II.
25.90	26.04

Calcic β-Chlordibromacrylate, $Ca(C_3ClBr_2O_2)_2 . 4 H_2O$. — On concentrating a solution of the calcium salt prepared by neutralizing a solution of the acid with calcic carbonate, the salt separated in clusters of branching needles, which were less soluble in water than the calcium salt of the α-acid.

I. 1.2644 grm. of the air-dried salt lost 0.1345 grm. H_2O at 80°.
II. 0.9273 grm. of the air-dried salt lost 0.1038 grm. H_2O at 80°.
III. 1.2124 grm. of the air-dried salt lost 0.1328 grm. H_2O at 80°.
IV. 0.8820 grm. of the anhydrous salt gave 0.1887 grm. $CaSO_4$.

	Calculated for $Ca(C_3ClBr_2O_2)_2 . 4\,H_2O$.	Found. I.	II.	III.
H_2O	11.27	10.64	11.19	10.91

	Calculated for $Ca(C_3ClBr_2O_2)_2$.	Found.
Ca	7.05	6.75

Potassic β-Chlordibromacrylate, $KC_3ClBr_2O_2$? — When a solution of the acid was neutralized with potassic carbonate, concentrated on the water bath, and evaporated to dryness over sulphuric acid, the potassium salt was left in the form of a very deliquescent amorphous mass. For analysis the salt was finally dried at 80°.

1.0509 grm. of the salt gave 0.4397 grm. K_2SO_4.

	Calculated for $KC_3ClBr_2O_2$.	Found.
K	12.92	12.42

All attempts to prepare a silver salt of this acid were unsuccessful. On the addition of argentic nitrate to a solution of the acid or any of its salts, the solution immediately became turbid from the separation of argentic bromide. This decomposition was not prevented to any appreciable extent by the exclusion of light.

Constitution of α- and β-Chlordibromacrylic Acids.

The essential points of difference in the physical properties of these acids, which appear in their general behavior and solubility in water, as well as in their melting points, would seem to point to a difference in structure. In the degree of hydration, solubility in water and comparative stability, their salts exhibit peculiarities as marked as those of the acids themselves. Although the silver salt of the α-acid can be prepared without difficulty, the corresponding salt of the β-acid cannot be formed even with the greatest care.

While the product obtained by the action of chlorine monobromide upon brompropiolic acid may have one of two forms, —

Brompropiolic Acid. α-Chlordibromacrylic Acid.

$$\begin{array}{lll} & \text{(1.)} & \text{(2.)} \\ \text{CBr} & \text{CBrCl} & \text{CBr}_2 \\ ||| & \| & \| \\ \text{C} & \text{CBr} & \text{CCl} \\ | & | & | \\ \text{COOH} & \text{COOH} & \text{COOH} \end{array}$$

the acid resulting from the abstraction of the elements of hydrobromic acid from chlortribrompropionic acid can evidently have but one: —

Chlortribrompropionic Acid.	β-Chlordibromacrylic Acid.
CBr_2Cl	$CBrCl$
|	‖
$CHBr$	CBr
|	|
$COOH$	$COOH$

Since the formula of β-chlordibromacrylic acid is identical with (1), the structure of the α-acid is probably represented by (2); or during the addition of chlorine monobromide to brompropiolic acid, the weaker halogen unites with the terminal carbon atom.

No. III.—ON β-DIBROMDICHLORPROPIONIC AND β-BROMDICHLORACRYLIC ACIDS.

By Charles F. Mabery and H. H. Nicholson.

β-Dibromdichlorpropionic Acid.

In a brief examination of the action of chlorine on β-dibromacrylic acid, it was found by F. C. Robinson and one of us,* that, although the acid was not affected at ordinary temperatures, an addition-product could readily be obtained by raising the temperature. Further study of this reaction shows that the most desirable results are obtained as regards time, as well as the quality and quantity of the product, if the temperature is kept near 100°. In one experiment after continuing the action for eight hours 5.9 grm. β-dibromacrylic acid gave 7.9 grm. of the crude β-dibromdichlorpropionic acid, which melted without purification above 90°, or ninety-six per cent of the amount of pure acid theoretically required.

The crude acid was easily purified by two or three crystallizations from a hot solution in carbonic disulphide, which deposited the greater part of the acid when cooled to 0°. It is but sparingly soluble in water, more soluble in hot than in cold chloroform, and very soluble in ether and alcohol. It crystallizes in oblique prisms, which melt at 100° and sublime slowly at higher temperatures. The composition of this acid was determined by the following analyses:—

I. 0.2142 grm. of the substance gave 0.4712 grm. AgCl + AgBr.
II. 0.8223 grm. of the substance gave 0.3485 grm. CO_2 and 0.0510 grm. H_2O.

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* These Proceedings, Vol. XVIII. p. 44.

	Calculated for $C_3H_2Cl_2Br_2O_2$.	Found. I.	II.
Cl + Br	76.74	76.67	
C	11.96		11.55
H	.66		.69

The salts of this acid are comparatively unstable. We were unable to prepare a silver salt in a form suitable for analysis, since argentic bromide began to separate as soon as argentic nitrate came in contact with the acid. Although there was no perceptible decomposition of the acid when it was treated in the cold with baric carbonate, several different preparations of the salt proved on analysis to contain a quantity of barium nearly three per cent in excess of the calculated value. In the preparation of the calcium and potassium salts we found less difficulty.

Calcic β-Dibromdichlorpropionate, $Ca(C_3Cl_2Br_2O_2H) . 1\frac{1}{2} H_2O$. — On treating the acid with calcic carbonate and calcic hydrate in the cold, filtering, and concentrating by spontaneous evaporation at the ordinary temperature, the calcium salt separated in clumps of needles. After drying to a constant weight in the air the salt lost one and a half molecules of crystal water at 80°.

I. 0.7775 grm. of the air-dried salt lost 0.0307 grm. H_2O at 80°,
II. 0.9392 grm. of the anhydrous salt lost 0.0403 grm. H_2O at 80°.
III. 0.8626 grm. of the anhydrous salt gave 0.1796 grm. $CaSO_4$.

	Calculated for $Ca(C_3HCl_2Br_2O_2)_2 . 1\frac{1}{2} H_2O$.	Found. I.	II.
H_2O	4.05	3.95	4.29
	Calculated for $Ca(C_3HCl_2Br_2O_2)_2$.		
Ca	6.25	6.13	

Potassic β-Dibromdichlorpropionate, $K(C_3HCl_2Br_2O_2)_2 . 2 H_2O$. — The potassium salt was made by neutralizing the acid with an aqueous solution of potassic carbonate and allowing it to evaporate without the application of heat. The air-dried salt contained two molecules of crystal water, which it lost over sulphuric acid.

I. 0.8735 grm. of the air-dried salt lost 0.0809 grm. H_2O over H_2SO_4.
II. 0.7933 grm. of the anhydrous salt gave 0.2171 grm. K_2SO_4.

	Calculated for $KC_3HCl_2Br_2O_2 . 2 H_2O$.	Found.
H_2O	9.66	9.26
	Calculated for $KC_3HCl_2Br_2O_2$.	
K	11.53	12.28

β-Bromdichloracrylic Acid.

β-dibromdichlorpropionic acid is readily decomposed by alkaline hydrates, and when the reaction is allowed to progress in the cold, the elements of hydrobromic acid are eliminated with the formation of the corresponding substituted acrylic acid. The best results were obtained by treating the acid with an aqueous solution of baric hydrate in slight excess over the calculated amount, and keeping the solution slightly alkaline for twenty-four hours. Upon acidifying this solution with hydrochloric acid, dichlorbromacrylic acid was partially precipitated as an oil, which solidified when cooled to 0°. Since the acid is quite soluble in water, the solution was extracted with ether, and the total product was purified by several crystallizations from hot water.

This acid is very soluble in hot, rather sparingly soluble in cold water, and very soluble in carbonic disulphide, chloroform, ether, and alcohol. It crystallizes from water in large pearly scales, which melt at 75°–78°. Its composition was determined by analysis.

I. 0.2374 grm. of the substance gave 0.5059 grm. AgCl + AgBr.
II. 0.2034 grm. of the substance gave 0.4377 grm. AgCl + AgBr.
III. 0.7255 grm. of the substance gave 0.4433 grm. CO_2 and 0.0337 grm. H_2O.

	Calculated for $C_3HCl_2BrO_2$.	Found. I.	II.	III.
2 Cl + Br	68.64	67.76	68.42	
C	16.36			16.66
H	.46			.52

In determining the solubility of this acid in cold water, a solution saturated at 20° was neutralized with baric carbonate, and the barium was determined in the filtered solution.

I. 6.0061 grm. of a solution saturated at 20° gave 0.1523 grm. $BaSO_4$.
II. 7.4519 grm. of a solution saturated at 20° gave 0.1872 grm. $BaSO_4$.

From these results the following percentages were calculated:—

I.	II.
4.79	4.74

This acid is characterized by a series of well-defined salts, several of which were prepared for analysis.

Baric β-Bromdichloracrylate, $Ba(C_3Cl_2BrO_2)_2 . 3 H_2O$. — The barium salt was made by neutralizing the acid in aqueous solution with

baric carbonate. It separated after concentration on the water-bath in prismatic crystals, which were less soluble in cold than in hot water.

I. 1.3622 grm. of the air-dried salt lost at 80° 0.1162 grm. H_2O.
II. 1.2529 grm. of the air-dried salt lost at 80° 0.1046 grm. H_2O.
III. 0.5757 grm. of the anhydrous salt gave 0.2353 grm. $BaSO_4$.

	Calculated for $Ba(C_3Cl_2BrO_2)_2 . 3 H_2O$.	Found. I.	II.
H_2O	8.58	8.53	8.35

	Calculated for $Ba(C_3Cl_2BrO_2)_2$.	III.
Ba	23.82	24.03

Calcic β-Bromdichloracrylate, $Ca(C_3Cl_2BrO_2)_2 . 3 H_2O$. — The calcium salt separated in the form of rhombic plates sparingly soluble in cold water, when an aqueous solution of the acid was neutralized with calcic carbonate and concentrated on the water-bath. For analysis it was dried first at a constant weight in the air, then at 80°.

I. 1.2318 grm. of the salt gave 0.1195 grm. H_2O at 80°.
II. 1.1054 grm. of the salt gave 0.1088 grm. H_2O at 80°.
III. 0.9719 grm. of the anhydrous salt gave 0.2741 grm. $CaSO_4$.

	Calculated for $Ca(C_3Cl_2BrO_2)_2 . 3 H_2O$.	Found. I.	II.
H_2O	10.15	9.71	9.85

	Calculated for $Ca(C_3Cl_2BrO_2)_2$.	III.
Ca	8.37	8.29

Potassic β-Bromdichloracrylate, $KC_3Cl_2BrO_2$. — The potassium salt was prepared by neutralization of the acid with potassic carbonate. After concentrating the solution the salt separated in minute prismatic crystals, which were very soluble in water. When dried to a constant weight in the air, it lost nothing at 80°.

1.2362 grm. of the salt dried at 80° gave 0.4144 grm. K_2SO_4.

	Calculated for $KC_3Cl_2BrO_2$.	Found.
K	15.15	15.03

Argentic β-Bromdichloracrylate, $AgC_3Cl_2BrO_2$. — The silver salt was thrown down as a flocculent precipitate upon the addition of argentic nitrate to an aqueous solution of the acid. This salt is permanent in ordinary daylight, and it can be recrystallized from hot water without

decomposition. It forms irregular rhombic plates, which are very slightly soluble in cold water.

0.6191 grm. of the salt dried over H_2SO_4 gave 0.2660 grm. AgCl.

	Calculated for $AgC_3Cl_2BrO_2$.	Found.
Ag	33.03	32.34

Since β-dibromacrylic acid has been shown* to have the structure represented by the formula,

$$\begin{array}{l} CBr_2 \\ \parallel \\ CH \\ | \\ COOH, \end{array}$$

the chlorine addition-product would naturally have the form,

$$\begin{array}{l} CBr_2Cl \\ | \\ CHCl \\ | \\ COOH, \end{array}$$

and to the corresponding β-bromdichloracrylic acid must be assigned the formula,

$$\begin{array}{l} CBrCl \\ \parallel \\ CCl \\ | \\ COOH. \end{array}$$

IV. — ON ORTHOIODTOLUOLSULPHONIC ACID.

By Charles F. Mabery and George H. Palmer.

Hübner and Glassner† found that, when paraiodtoluol was dissolved in chloroform and treated with the calculated amount of sulphuric anhydride, two acids were formed, which they called α- and β-paraiodsulfitoluols. On trying the same reaction with orthoiodtoluol prepared from orthotoluidin by means of the diazo reaction, we were unable to effect any change in a chloroform solution, either in the cold or by the application of heat. But when sulphuric anhydride freshly distilled

* H. B. Hill, these Proceedings, Vol. XVII. p. 151.

† Berichte deutschen Chem. Gesellsch., viii. 560.

from Nordhausen sulphuric acid was added cautiously to the iodtoluol, at first keeping the mixture cold, and finally heating it for some time, the reaction was easily accomplished. To separate the resulting product from the acid mixture it was treated with an excess of baric carbonate, heated to boiling, filtered, and concentrated on the water-bath. On cooling, the barium salt of orthoiodtoluolsulphonic acid separated in clusters of needles, which were much less soluble in cold than in hot water. So far as it could be determined by any difference in solubility or crystalline form of the barium salt, only one acid was formed. By precipitating carefully with sulphuric acid the barium from a solution of the barium salt, and concentrating the filtered solution on the water-bath, the acid was left as an oily liquid, which did not solidify when cooled to 0°, or on long standing over sulphuric acid.

Baric Orthoiodtoluolsulphonate, $Ba(C_7H_6ISO_3)_2 . 1\frac{1}{2} H_2O$. — For analysis the barium salt was prepared as above described, and dried at first in the air, then at 100°.

I. 1.2312 grm. of the air-dried salt lost 0.0407 grm. H_2O at 100°.
II. 0.8011 grm. of the air-dried salt lost 0.0300 grm. H_2O at 100°.
III. 0.5967 grm. of the anhydrous salt gave 0.1888 grm. $BaSO_4$.

	Calculated for $Ba(C_7H_6ISO_3)_2 . 1\frac{1}{2} H_2O$.	Found. I.	II.
H_2O	3.54	3.31	3.66

	Calculated for $Ba(C_7H_6ISO_3)_2$.	Found.
Ba	18.61	18.03

Calcic Orthoiodtoluolsulphonate, $Ca(C_7H_6ISO_3)_2 . 2\frac{1}{2} H_2O$. — This salt was prepared by neutralizing the free acid with calcic carbonate, and evaporating the filtered solution on the water-bath. The air-dried salt was heated to 100°.

I. 0.6243 grm. of the air-dried salt lost 0.0414 grm. H_2O at 100°.
II. 0.6250 grm. of the air-dried salt lost 0.0424 grm. H_2O at 100°.

	Calculated for $Ca(C_7H_6ISO_3)_2 . 2\frac{1}{2} H_2O$.	Found. I.	II.
H_2O	6.62	6.61	6.78

0.7298 grm. of the anhydrous salt gave 0.1762 grm. $CaSO_4$.

	Calculated for $Ca(C_7H_6ISO_3)_2$.	Found.
Ca	6.31	7.10

Plumbic Orthoiodtoluolsulphonate, $Pb(C_7H_6ISO_3)_2 . 2 H_2O$. — The lead salt was formed by treating the free acid with plumbic carbonate,

filtering, and evaporating on the water-bath. The air-dried salt lost two molecules of crystal water at 100°.

I. 1.2580 grm. of the air-dried salt lost 0.0562 grm. H_2O at 100°.
II. 1.2538 grm. of the air-dried salt lost 0.0512 grm. H_2O at 100°.
III. 0.7176 grm. of the air-dried salt lost 0.0294 grm. H_2O at 100°.
IV. 0.6163 grm. of the anhydrous salt gave 0.2318 grm. $PbSO_4$.
V. 0.6455 grm. of the anhydrous salt gave 0.2425 grm. $PbSO_4$.

	Calculated for $Pb(C_7H_6ISO_3)_2\ 2\,H_2O$.	Found. I.	II.	III.
H_2O	4.30	4.47	4.01	4.10

	Calculated for $Pb(C_7H_6ISO_3)_2$.	V.	VI.
Pb	25.78	25.75	25.72

An analysis of the free acid gave a percentage of iodine somewhat lower than the calculated value, but further study of it was prevented by the closing of the summer term.

XII.

RECENT OBSERVATIONS OF VARIABLE STARS.

By Edward C. Pickering.

Presented March 12, 1884.

The work of observing variable stars is a branch of astronomical research which can be successfully prosecuted at observatories not provided with the means for undertaking large pieces of routine work. Hence, where these means exist, the observation of variable stars is usually neglected, not from any doubt of its interest or importance, but because it is assumed that attention will be paid to it at institutions less fully equipped, and especially by the numerous amateur observers to whose resources it appears so well adapted.

But in order to obtain the best results in this line of research, some systematic division of the labor has become important. At present, for want of system, some variable stars are observed with unnecessary frequency, while others of no less interest are completely neglected. A bibliography of the variable stars, which is in course of preparation by Mr. S. C. Chandler, Jr., will exhibit large gaps in the observations of many important objects in the list. In such cases, the value of the earlier observations is often impaired by the difficulty of connecting them with those recently made.

In the hope of promoting a more systematic observation of the variable stars, a pamphlet upon the subject, and a subsequent circular, have been issued during the past year by the Harvard College Observatory. In response to the recommendations of the pamphlet, a number of observers signified their inclination to undertake the proposed work, some of whom have already reported many valuable observations. It is to be anticipated that their example will be followed by others, so that the frequent renewal of the special lists of stars required by each participant in the work will become inconvenient. Under these circumstances it seems desirable to make a published statement of the present condition of this branch of scientific inquiry, so that each observer may judge for himself what part of the work can be most profitably undertaken with the means at his disposal. This advantage would

obviously be lost by waiting for the reduction and publication of the observations. It is intended to publish another circular early in 1885, giving, so far as practicable, the results obtained during 1884 by all observers of variable stars. The value of this circular will depend upon the amount of assistance which the various astronomers interested in the subject may be inclined to afford. Those who have already undertaken to communicate their observations to this Observatory will, no doubt, continue their co-operation. If the greater part of the results obtained by independent observation elsewhere are also communicated in a form so far condensed that they can be furnished with little trouble to the observers themselves, the proposed circular will exhibit a statement of the course of observation during the year sufficiently complete to form a highly useful guide for subsequent work. It is therefore hoped that observers of variable stars, whether professional astronomers or amateurs, will be generally disposed to furnish the information necessary to the completeness of the circular. This information relates to the following subjects: —

1. Method of observation. If photometric, some account of the instrument and the manner of using it. If not photometric, whether the observations are made by Argelander's method, by the division into tenths of the interval in brightness between two comparison stars, one slightly brighter and the other slightly fainter than the star observed, or by direct estimation of magnitude.

2. Stars observed during 1884, and the number of nights on which each was observed. In naming the stars, it may be convenient to use the numbers given in the first column of Table I. below.

3. The time and form of publication of the observations now contemplated by the observer.

4. Plans for 1885, with regard to the stars selected for observation, and the number of nights on which it is proposed that each shall be observed.

Further information, although not directly required for the purpose of the circular, will be gratefully received. If the observations are not to be published by the observer, a copy of them would be most acceptable. If they are, any results already reached, as, for example, the times and magnitudes of the maxima and minima of the stars, the dates of the separate observations, or the number of nights in each month of the year upon which a given star was observed, would be of much service.

Table I. exhibits the results of observation of variable stars for 1883, so far as they are at hand, in order to show the nature of the

TABLE I. — Variable Stars.

No.	H.P.	Name.	R. A. 1875.	Dec. 1875.	Max.	Min.	Per.
			h. m. s.	° ′	m.	m.	d.
0a	—	Ceti	0 15 26	−20 45.1	5.2	7.0	—
1	51	T Cassiopeiæ	16 29	+55 5.9	6.5 — 7.0	11 — 11.2	436
2	54	R Andromedæ	17 28	+37 53.0	5.6 — 8.6	<12.8	404.7
3	—	S Ceti	17 42	−10 14.5	7.0 — 8.0	<10.7	323.6
4	—	B Cassiopeiæ	17 52	+63 27.2	>1	?	—
5	—	T Piscium	25 31	+13 54.6	9.5 — 10.2	10.5 — 11.0	Irr.
6	94	α Cassiopeiæ	33 25	+55 51.1	2.2	2.8	Irr.
6a	—	U Cephei	51 18	+81 12.1	7.0	9.5	2.5
7	—	S Cassiopeiæ	1 10 30	+71 57.2	6.7 — 8.5	<13	615
8	—	S Piscium	11 2	+ 8 16.3	8.8 — 9.3	<13	406.6
8a	—	Piscium	16 22	+14* 12.7	10	14	—
8b	—	Ceti	19 31	− 4 36.6	6.5	7.8	—
8c	—	R Sculptoris	21 13	−33 11.5	5½	7½	207
9	—	R Piscium	24 12	+ 2 14.1	7.4 — 8.3	<12.5	345
10	—	S Arietis	57 55	+11 55.5	9.1 — 9.8	<13	288.8
11	—	R Arietis	2 9 1	+24 28.4	7.6 — 8.5	11.9 — 12.7	186.2
12	370	o Ceti	13 1	− 3 43.9	1.7 — 5.0	8 — 9	331.3
13	—	S Persei	13 54	+58 0.8	8.5 ?	<9.7	—
14	—	R Ceti	19 39	− 0 55.7	7.9 — 8.7	<12.8	167.1
15	—	T Arietis	41 22	+16 59.3	7.9 — 8.2	9.4 — 9.7	324
16	489	ρ Persei	57 10	+38 21.3	3.4	4.2	Irr.
17	496	β Persei	3 0 2	+40 28.4	2.2	3.7	2.9
18	—	R Persei	22 6	+35 14.3	8.1 — 9.2	12.5	208.8
19	657	λ Tauri	53 45	+12 8.2	3.4	4.2	4.0
20	—	T Tauri	4 14 43	+19 14.8	9.2 — 11.5	12.8 — <	Irr.
21	—	R Tauri	21 27	+ 9 52.9	7.4 — 9.0	<13	325.6
22	—	S Tauri	22 22	+ 9 40.1	9.9	<13	378
22a	—	Doradus	35 19	−62 19.4	5½	6½	—
23	—	V Tauri	44 48	+17 19.6	8.3 — 9.0	<12.8	168.6
24	—	R Orionis	52 13	+ 7 56.8	8.7 — 8.9	<13	378.8
25	877	ε Aurigæ	53 0	+43 38.2	3.0	4.5	Irr.
26	880	R Leporis	53 55	−15 3.7	6 — 7	8.5 ?	437.8
27	—	R Aurigæ	5 7 12	+53 26.6	6.5 — 7.4	12.5 — 12.7	465
27a	—	S Aurigæ	18 52	+34 2.3	9.4	<13	—
28	—	S Orionis	22 50	− 4 49.9	8.3 ?	<12.3	—
29	1005	δ Orionis	25 37	− 0 25.6	2.2 ?	2.7	Irr.
29a	—	Orionis	29 42	− 5 33.5	10	13	—
30	1091	α Orionis	48 24	+ 7 23.3	1	1.4	Irr.
31	1160	η Geminorum	6 7 20	+22 22.4	3.2	3.7 — 4.2	229.1
31a	—	Monocerotis	16 26	− 2 8.1	7	<10	—
32	1205	T Monocerotis	18 29	+ 7 9.1	6.2	7.6	26.8
33	—	R Monocerotis	32 21	+ 8 50.7	9.5	11.5	Irr.
34	1256	S Monocerotis	34 6	+10 0.5	4.9	5.4	3.4
35	—	R Lyncis	50 59	+55 30.2	9 ?	<12.8	—
36	1334	ζ Geminorum	56 41	+20 45.1	3.7	4.5	10.2
37	—	R Geminorum	59 49	+22 58.8	6.6 — 7.8	<12.3	371.0
38	—	R Canis min.	7 1 50	+10 13.1	7.2 — 7.9	9.5 — 10.0	335.0
38a	—	Puppis	9 43	−44 26.2	3½	<6	135
38b	—	V Geminorum	16 10	+13 21.8	8.5	12 — 13½	276
38c	1417	U Monocerotis	24 50	− 9 31.0	6.0	7.2	46.0
39	—	S Canis min.	25 56	+ 8 35.0	7.2 — 8.0	<11	332.2
40	—	T Canis min.	27 3	+12 0.6	9.1 — 9.7	<13	335.2
40a	—	Canis min.	34 34	+ 8 40.2	8½	13.5	405

* Declination +12° 12′.7, according to Mr. Parkhurst.

TABLE I. — Variable Stars.

No.	Class.	Discoverer.	Date.	Obs. 1883.	Obs. 1880–82.
0a	—	Chandler	1881	2 C. 36 S.	—
1	II.	Krüger	1870	14 C.	W.
2	II.	Argelander	1858	12 C.	Sm. W.
3	II.	Borelly	1872	6 C.	Sf. W.
4	I.	Tycho Brahe	1572	—	—
5	II.	Luther	1855	6 C.	—
6	III.	Birt	1831	—	Sm. W.
6a	V.	Ceraski	1880	—	Sm. W.
7	II.	Argelander	1861	15 C. 26 P. 8 S.	Sf. Sm. W.
8	II.	Hind	1851	7 C.	Sm.
8a	—	Peters	1880	—	—
8b	—	Gould	1874?	—	—
8c	II.	Gould	1872?	—	—
9	II.	Hind	1850	9 C.	Sm. W.
10	II.	Peters	1865	6 C.	—
11	II.	Argelander	1857	7 C. 19 H. 1 Z.	Sm. W.
12	II.	Fabricius	1596	5 C.	Sm.
13	II.	Krüger	1873	13 C. 17 H.	Sf.
14	II.	Argelander	1866	4 C.	—
15	II.	Auwers	1870	10 C. 24 H. 7 Z.	—
16	II.?	Schmidt	1854	35 S.	Sm.
17	V.	Montanari	1669	—	Müller, Sm. W.
18	II.	Schönfeld	1861	7 C. 6 H.	H. Sm. W.
19	V.	Baxendell	1848	—	—
20	—	Hind	1861	7 C.	—
21	II.	Hind	1849	10 C.	Sf. Sm. W.
22	II.	Oudemans	1855	10 C.	Sf. W.
22a	—	Gould	1874?	7 L. 9 U.	—
23	II.	Auwers	1871	13 C. 6 P.	H. Sf. W.
24	II.	Hind	1848	11 C.	H. Sf. W.
25	III.	Fritsch	1821	10 S.	Sm.
26	II.	Schmidt	1855	7 C. 22 S.	Sm.
27	II.	At Bonn	1862	9 C. 26 H.	Sf. Sm.
27a	II.	Dunér	1881	10 C. 8 P.	D. Sm.
28	II.	Webb	1870	10 C.	Sf.
29	III.	J. Herschel	1834	8 S.	—
29a	—	Bond	1863	6 C.	Müller
30	III.	J. Herschel	1836	—	Sm.
31	II.?	Schmidt	1866	—	Sm.
31a	—	Schönfeld	1883	2 C.	—
32	IV.	Gould	1871	61 S.	W.
33	II.	Schmidt	1861	11 C.	Sm.
34	IV.	Winnecke	1867	8 S.	—
35	II.	Krüger	1874	12 C. 14 P.	H.
36	IV.	Schmidt	1844	—	Sm.
37	II.	Hind	1848	14 C. 19 P. 26 S.	W.
38	II.	At Bonn	1854	16 C. 8 H. 3 Z.	Sf. W.
38a	II.	Gould	1872	10 L. 12 U.	—
38b	II.	Baxendell	1880	17 C.	Baxendell
38c	II.?	Gould	1873	36 S.	—
39	II.	Hind	1856	14 C.	Sf. W.
40	II.	Schönfeld	1865	9 C.	—
40a	II.	Baxendell	1879	9 C.	Sm.

TABLE I. — *Continued.*

No.	H.P.	Name.	R. A. 1875.	Dec. 1875.	Max.	Min.	Per.
			h. m. s.	° ′	m.	m.	d.
41	—	S Geminorum	7 35 32	+28 44.6	8.2 — 8.7	<13	294.2
42	—	T Geminorum	41 48	+24 2.7	8.1 — 8.7	<13	288.1
42*a*	—	S Puppis	43 6	—47 8.8	$7\frac{1}{4}$	9	—
43	—	U Geminorum	47 41	+22 19.7	8.9 — 9.7	13.1	Irr.
43*a*	—	Puppis	55 0	—12 32	$8\frac{1}{2}$	<14	310
44	—	R Cancri	8 9 40	+12 6.5	6.2 — 8.3	<11.7	354.4
45	—	V Cancri	14 36	+17 40.9	6.8 — 7.2	<12	272
46	—	U Cancri	28 37	+19 19.5	8.2 — 10.4	<13	305.7
47	—	S Cancri	36 48	+19 29.0	8.2	9.8	9.5
48	—	S Hydræ	47 3	+ 3 32.4	7.5 — 8.5	<12.2	256.4
49	—	T Cancri	49 32	+20 19.7	8.2 — 8.5	9.3 — 10.5	484.2
50	—	T Hydræ	49 35	— 8 31.0	7.0 — 8.1	<12.5	280.4
50*a*	—	R Carinæ	9 29 6	—62 14.2	4.4	9.3	313
51	—	R Leonis min.	38 4	+35 5.2	6.1 — 7.5	<11.0	374.7
52	1752	R Leonis	40 50	+12 0.5	5.2 — 6.4	9.4 — 10.0	312.6
52*a*	—	l Carinæ	41 49	—61 55.9	3.7	5.2	31.2
52*b*	—	Leonis	53 8	+21 51.6	$8\frac{1}{3}$	8.6<13	280 ?
52*c*	—	Antliæ	10 4 22	—37 7.1	$6\frac{1}{3}$	<8	—
52*d*	—	Carinæ	5 23	—60 56.3	$6\frac{1}{4}$	9	—
52*e*	—	U Leonis	17 21	+14 38.1	$9\frac{1}{2}$	Inv.	—
52*f*	1869	Hydræ	31 22	—12 44.1	$4\frac{1}{3}$	6	—
53	1880	R Ursæ maj.	35 47	+69 25.9	6.0 — 8.1	12	303.4
54	—	η Argus	40 13	—58 49.2	>1	6.3	Irr.
54*a*	—	T Carinæ	50 18	—59 51.2	6.2	6.9	—
55	—	R Crateris	54 25	—17 26.4	>8	<9	—
56	—	S Leonis	11 4 23	+ 6 8.5	9.0 — 9.7	<13	187.6
57	—	T Leonis	32 2	+ 4 3.9	10 ?	<13	—
58	—	X Virginis	55 27	+ 9 46.1	7.8 ?	<10	—
59	—	R Comæ	57 51	+19 28.8	7.4 — 8.0	<13	363
60	—	T Virginis	12 8 12	— 5 7.2	8.0 — 8.8	<13	337
61	—	R Corvi	13 10	—18 20.3	6.8 — 7.3	<11.5	318.6
61*a*	—	— Virginis	27 26	— 3 43.8	8	14	210±
62	—	T Ursæ maj.	30 42	+60 10.6	7.0 — 8.3	12.2	255.6
63	2147	R Virginis	32 10	+ 7 40.6	6.5 — 7.5	10.0 — 10.9	145.7
63*a*	—	R Muscæ	34 28	—68 43.3	6.6	7.3	0.9
64	—	S Ursæ maj.	38 28	+61 46.7	7.7 — 8.2	10.2 — 11.1	224.8
65	—	U Virginis	44 46	+ 6 14.0	7.7 — 8.1	12.2 — 12.8	207.4
66	—	W Virginis	13 19 35	— 2 31.2	8.7 — 9.2	9.8 — 10.4	17.3
67	—	V Virginis	21 21	— 2 19.0	8.0 — 9.0	<13	251
68	2275	R Hydræ	22 53	—22 25.6	4.0 — 5.5	10 ?	469.3
69	2289	S Virginis	26 29	— 6 20.6	5.7 — 7.8	12.5	374.0
69*a*	—	Virginis	14 3 37	—12 42.7	9	14	—
69*b*	—	R Centauri	7 35	—59 19.8	6	10	—
70	—	T Bootis	8 14	+19 39.1	9.7 ?	<13	—
71	—	S Bootis	18 41	+54 22.7	8.1 — 8.5	13.2	272.4
72	—	R Camelopardi	27 8	+84 23.8	7.9 — 8.6	12 ?	266.2
73	2445	R Bootis	31 41	+27 16.9	5.9 — 7.5	11.3 — 12.2	223.0
73*a*	2459	Bootis	37 56	+27 3.6	5.2	6.1	370 ?
73*b*	—	Bootis	48 33	+18 12.1	9.1	12.0 — 13.6	173.8
74	2506	δ Libræ	54 18	— 7 51.6	4.9	6.1	2.3
74*a*	—	Libræ	15 3 37	—19 33.9	10	<13.5	700±
74*b*	—	R Triang. Austr.	8 37	—66 2.1	6.6	8.0	3.4
75	—	U Coronæ	13 6	+32 6.4	7.6	8.8	3.5
76	—	S Libræ	14 13	—19 47.3	8.0	12.5 ?	—
77	—	S Serpentis	15 48	+14 45.9	7.6 — 8.6	12.5 ?	361.0

TABLE I. — *Continued.*

No.	Class.	Discoverer.	Date.	Obs. 1883.	Obs. 1880–82.
41	II.	Hind	1848	6 C.	Sf. W.
42	II.	Hind	1848	7 C.	Sf. W.
42*a*	—	Gould	1874?	—	—
43	II. ?	Hind	1855	24 C.	H. Sf.
43*a*	II.	Pickering	1881	12 C.	—
44	II.	Schmidt	1829	18 C.	Sm. W.
45	II.	Auwers	1870	15 C. 18 P. 21 S.	Sm. W.
46	II.	Chacornac	1853	11 C.	Sm.
47	V.	Hind	1848	—	Sm.
48	II.	Hind	1848	12 C.	D. Sf.
49	II.	Hind	1850	14 C. 14 P.	—
50	II.	Hind	1851	11 C.	Sf. W.
50*a*	II.	Gould	1871	—	—
51	II.	Schönfeld	1863	10 C. 22 S.	Sm.
52	II.	Koch	1782	12 C. 14 S.	D. Sf. Sm.
52*a*	—	Gould	1871	16 L. 17 U.	—
52*b*	II.	Becker	1882	8 C.	Becker
52*c*	—	Gould	1872	—	—
52*d*	—	Gould	1871	—	—
52*e*	—	Peters	1876	7 C.	—
52*f*	—	Gould	1871	—	—
53	II.	Pogson	1853	14 C. 31 H. 23 S. 7 Z.	Sm. W.
54	II.?	Burchell	1827	—	—
54*a*	—	Thome	1872	10 L. 11 U.	—
55	II.	Winnecke	1861	10 C.	Sf.
56	II.	Chacornac	1856	13 C.	—
57	II.	Peters	1865	4 C.	—
58	II.	Peters	1871	9 C.	—
59	II.	Schönfeld	1856	8 C. 30 P.	—
60	II.	Boguslawski	1849	5 C.	—
61	II.	Karlinski	1867	9 C.	Sf.
61*a*	II.	Henry	—	11 C.	—
62	II.	Hencke	1856	17 C. 39 S.	H. Sf. Sm. W.
63	II.	Harding	1809	17 C. 26 S.	H. Sm. W.
63*a*	IV.	Gould	1871	10 L. 16 U.	—
64	II.	Pogson	1853	17 C. 35 S.	D. Sf. Sm. W.
65	II.	Harding	1831	14 C.	D. Sm. W.
66	II.?	Schönfeld	1866	12 C.	D.
67	II.	Goldschmidt	1857	10 C. 22 P.	W.
68	II.	Miraldi	1704	2 C. 41 S.	D. Sm. T.
69	II.	Hind	1852	12 C.	—
69*a*	II.	Palisa	1880	7 C.	—
69*b*	—	Gould	1871	9 L. 11 U.	—
70	I.?	Baxendell	1860	—	—
71	II.	At Bonn	1860	15 C.	D. Sm.
72	II.	Hencke	1858	7 C.	Sf. Sm.
73	II.	At Bonn	1858	15 C. 32 S.	Sm. W.
73*a*	—	Schmidt	1867	—	—
73*b*	II.	Baxendell	1880	11 C.	Baxendell
74	V.	Schmidt	1859	—	Sm.
74*a*	II.	Palisa	1878	5 C.	Palisa, Weis
74*b*	IV.?	Gould	1871	2 L. 6 U.	—
75	V.	Winnecke	1869	—	Sm.
76	II.	Borelly	1872	6 C.	Sf.
77	II.	Harding	1828	6 C.	D.

TABLE I. — *Continued.*

No.	H.P.	Name.	R. A. 1875.	Dec. 1875.	Max.	Min.	Per.
			h. m. s.	° ′	m.	m.	d.
78	2553	S Coronæ	15 16 18	+31 49.1	6.1 — 7.8	11.9 — 12.5	361.0
78*a*	—	Libræ	34 46	—20 46.5	9	<14	—
79	2639	R Coronæ	43 25	+28 32.5	5.8	13.0	Irr.
80	2647	R Serpentis	44 56	+15 30.8	5.6 — 7.6	<11	357.6
80*a*	—	V Coronæ	45 4	+39 57.0	7.7	12	360.0
81	—	R Libræ	46 32	—15 44 5	9.2 — 10.0	<13	723
82	2678	T Coronæ	54 16	+26 16.5	2.0	9.5	—
83	—	R Herculis	16 0 37	+18 42.5	8.0 — 9.0	<13	319.0
83*a*	—	W Scorpii	4 28	—19 48.6	10	<13	224.3
84	—	T Scorpii	9 36	—22 33.5	7	<10	—
85	—	R Scorpii	10 12	—22 31.8	9 ? — 10.5	<12.5	228
86	—	S Scorpii	10 13	—22 28.8	9.1 — 10.5	<12.5	176.9
86*a*	—	Ophiuchi	14 40	— 7 24.0	9.0	<13.5	326
87	—	U Scorpii	15 16	—17 29.3	9 ?	<12	—
87*a*	—	Ophiuchi	19 46	—12 8.5	7.5	10.5	365
88	—	U Herculis	20 16	+19 10.8	6.6 — 7.7	11.4 — 11.6	408.3
89	2772	g Herculis	24 32	+42 9.6	5	6.2	Irr.
90	—	T Ophiuchi	26 35	—15 46.6	10	<12.5	—
91	—	S Ophiuchi	27 4	—16 48.5	8.3 — 9.0	<12.5	233.8
91*a*	—	W Herculis	30 48	+37 35.6	8.0	<14.5	289
91*b*	—	Urs. Min.	31 40	+72 31.9	8.6	10.5	180 ?
91*c*	—	R Draconis	32 22	+67 0.7	7.2	13<	245.9
92	2828	S Herculis	46 13	+15 9.2	5.9 — 6.8	11.5 — 12.2	303
93	2839	Ophiuchi	52 30	—12 38.0	5.5	12.5	—
93*a*	—	V Herculis	53 41	+35 15.5	9.0	11.7	—
94	—	R Ophiuchi	17 0 36	—15 51.9	7.6 — 8.1	<12	302.4
95	2879	α Herculis	8 57	+14 32.1	3.1	3.9	Irr.
95*a*	2883	U Ophiuchi	10 12	+ 1 21.0	6.1	6.8	0.9
96	2890	u Herculis	12 42	+33 14.1	4.6	5.4	38.5
97	—	Serpentarii	23 9	—21 20.0	>1	?	—
98	2972	X Sagittarii	39 41	—27 45.6	4	6	7.0
99	3035	W Sagittarii	57 2	—29 34.7	5	6.5	7.6
100	—	T Herculis	18 4 22	+31 0.1	7.2 — 8.3	11.4 — 12.1	165.1
101	—	T Serpentis	22 43	+ 6 13.1	9.1 — 10.0	<12.8	342.3
102	—	V Sagittarii	24 4	—18 22.1	7.5 ?	9.5 ?	—
103	—	U Sagittarii	24 32	—19 13.9	7.0	8.3	6.7
104	—	T Aquilæ	39 45	+ 8 36.9	8.8	9.5	Irr.
105	3176	R Scuti	40 49	— 5 52.6	4.7 — 5.7	6.0 — 8.5	71.1
105*a*	—	κ Pavonis	44 3	—67 23.2	4.0	5.5	9.1
106	3193	β Lyræ	45 28	+33 13.0	3.4	4.5	12.9
107	3224	R Lyræ	51 32	+43 47.1	4.3	4.6	46.0
108	—	S Coron. Austr.	52 43	—37 10.0	9.8	11.5 ?	6.1
109	—	R Coron. Austr.	53 29	—37 10.4	10.5 — 11.5	<12.5	31
110	—	R Aquilæ	19 0 21	+ 8 2.6	6.4 — 7.4	10.9 — 11.2	345.1
111	—	T Sagittarii	9 1	—17 15.2	7.6 — 8.1	<11	381
112	—	R Sagittarii	9 21	—19 35.5	7.0 — 7.2	<12	270.0
113	—	S Sagittarii	12 7	—19 19.1	9.7 — 10.4	<12.7	230
114	3395	R Cygni	33 28	+49 55.1	5.9 — 8.0	13	425.3
115	—	R Vulpeculæ	42 26	+27 0.5	8	?	—
116	—	S Vulpeculæ	43 16	+26 58.7	8.4 — 8.9	9.0 — 9.5	67.5
117	3484	χ Cygni	45 46	+32 36.0	4.0 — 6.0	12.8	406.5
118	3436	η Aquilæ	46 6	+ 0 41.2	3.5	4.7	7.2
119	—	S Cygni	20 2 53	+57 37.6	8.8 — 9.5	<13	322.8
120	—	R Capricorni	4 17	—14 45.0	8.8 — 9.7	<13	347
121	—	S Aquilæ	5 52	+15 14.9	8.9 — 9.9	10.7 — 11.8	147.2

TABLE I. — *Continued.*

No.	Class.	Discoverer.	Date.	Obs. 1883.	Obs. 1880–82.
78	II.	Hencke	1860	13 C. 43 S.	H. Sm. W.
78*a*	—	Peters	1878	—	—
79	II.?	Pigott	1795	14 C. 56 S.	Sm. W.
80	II.	Harding	1826	10 C.	Sm.
80*a*	II.	Dunér	1878	18 C.	H. Sf. Sm. W.
81	II.	Pogson	1858	2 C.	—
82	I.	Birmingham	1866	—	Sm.
83	II.	At Bonn	1855	12 C. 4 H.	H. Sm.
83*a*	II.	J. Palisa	1877	3 C.	Sm.
84	I.	Auwers	1860	2 C.	—
85	II.	Chacornac	1853	7 C.	Sm.
86	II.	Chacornac	1854	6 C.	Sm.
86*a*	II.	Schöneld	1881	8 C.	Sm.
87	I.?	Pogson	1868	—	—
87*a*	—	Dunér	1881	3 C.	Dreyer, D.
88	II.	Hencke	1860	14 C. 84 S.	Sm.
89	III.	Baxendell	1857	69 S.	Sm.
90	II.	Pogson	1860	4 C.	—
91	II.	Pogson	1854	4 C.	—
91*a*	—	Dunér	1880	—	D. W.
91*b*	II.	Pickering	1881	20 C.	Pickering
91*c*	II.	Geelmuyden	1876	18 C. 21 S.	H. Sm. W.
92	II.	At Bonn	1856	10 C. 25 H.	H. Sm. W.
93	I.	Hind	1848	—	—
93*a*	II.	Baxendell	1880	11 C.	Baxendell
94	II.	Pogson	1858	7 C.	D.
95	III.	W. Herschel	1795	—	Sm.
95*a*	V.	Sawyer	1881	12 S.	—
96	III.	Schmidt	1869?	—	Sm.
97	I.	Fabricius	1604	—	—
98	IV.	Schmidt	1866	16 S.	Sm.
99	IV.	Schmidt	1866	44 S.	Sm.
100	II.	At Bonn	1857	18 C. 13 H.	H. Sm. W.
101	II.	Baxendell	1860	10 C.	—
102	II.	Quirling	1865	6 C.	—
103	IV.	Schmidt	1866	5 C.	Sm.
104	II.	Winnecke	1860	9 C.	—
105	II.	Pigott	1795	3 C. 79 S.	Sm. W.
105*a*	IV.	Thome	1872	1 U.	—
106	IV.	Goodricke	1784	—	Müller, Sm. W.
107	II.?	Baxendell	1856	17 S.	—
108	IV.?	Schmidt	1866	1 C.	Sm.
109	II.?	Schmidt	1866	1 C.	Sm.
110	II.	At Bonn	1856	1 C.	—
111	II.	Pogson	1868	6 C.	Sf.
112	II.	Pogson	1858	7 C.	D.
113	II.	Pogson	1860	7 C.	—
114	II.	Pogson	1852	14 C. 22 P. 17 H. 6 Z.	Sm. W.
115	I.	Anthelm	1670	—	—
116	II.	Hind	1861	12 C. 26 H. 4 Z.	W.
117	II.	Kirch	1686	11 C. 55 P. 26 H. 67 S. 4 Z.	Sm. W.
118	IV.	Pigott	1784	16 S.	Sm. W.
119	II.	At Bonn	1860	9 C. 15 P.	Sf.
120	II.	Hind	1848	6 C.	D.
121	II.	Baxendell	1863	10 C.	—

TABLE I. — *Continued.*

No.	H P.	Name.	R. A. 1875.	Dec. 1875.	Max.	Min.	Per.
			h. m. s.	° ′	m.	m.	d.
122	—	R Sagittæ	20 8 22	+16 21.0	8.5 — 8.7	9.8 — 10.4	70.4
123	—	R Delphini	8 53	+ 8 42.7	7.6 — 8.5	12.8	284.0
124	3547	P Cygni	13 11	+37 38.7	3 — 5	<6	—
125	—	U Cygni	15 44	+47 30.1	7.8?	9.8?	—
126	3557	R Cephei	34 29	+88 45.2	5?	10?	—
126a	—	— Cygni	37 17	+47 41.8	8	12	423.
127	—	S Delphini	37 19	+16 38.4	8.4 — 8.6	10.4 — 11.1	275.6
128	—	T Delphini	39 34	+15 56.7	8.2 — 8.9	<13	331.4
129	—	U Capricorni	41 11	—15 23.2	10.2 — 10.8	<13	203.5
130	3654	T Cygni	42 12	+33 55.0	5.5?	6?	—
131	—	T Aquarii	43 20	— 5 45.3	6.7 — 7.0	12.4 — 12.7	203.2
132	—	R Vulpeculæ	58 49	+23 19.5	7.5 — 8.5	12.5 — 13.0	137.5
132a	—	Capricorni	21 0 19	—24 25.5	9½	14	—
132b	—	T Cephei	7 52	+67 58.9	5.6	9.5	382
133	—	T Capricorni	15 6	—15 51.4	8.9 — 9.7	<13	269.4
134	—	S Cephei	36 45	+78 3.6	7.4 — 8.5	11.5	485
134a	—	Nova Cygni	37 2	+42 18.2			—
135	3845	μ Cephei	39 41	+58 12.4	4?	5?	Irr.
136	—	T Pegasi	22 2 48	+11 55.7	8.8 — 9.8	<12.5	367.5
137	3981	δ Cephei	24 32	+57 46.6	3.7	4.9	5.4
137a	—	Lacertæ	37 43	+41 43.0	8.6	<13.5	315.
138	—	S Aquarii	50 25	—21 13.4	7.7 — 9.1	<11.5	279.4
139	4078	β Pegasi	57 45	+27 24.2	2.2	2.7	Irr.
140	—	R Pegasi	23 0 22	+ 9 52.1	6.9 — 7.7	12?	382.0
141	—	S Pegasi	14 14	+ 8 14.2	7.6	<12.2	—
142	4193	R Aquarii	37 21	—16 11.9	5.8 — 8.5	11?	388.0
143	4234	R Cassiopeiæ	52 4	+50 41.5	4.8 — 6.8	<12	425.9

information desired. It is thought best not to delay the publication of the present circular in order to obtain additional information, much of which must be procured from Europe; but astronomers will confer a favor upon this Observatory by sending material which may be used next year to make the table for 1883 more complete. It is highly desirable that this information, as well as that respecting the observations of 1884, should reach this Observatory as early as February 1, 1885, in order that the proposed circular may be issued as early in the year as possible. Information received later, however, may be made serviceable in any circular which may afterwards be prepared.

The bibliography undertaken by Mr. Chandler, as above mentioned, will eventually furnish the means of preparing a catalogue of all the stars now known to be variable. The list in Table I. is from his provisional catalogue of known variables, which consists of Schönfeld's Second Catalogue,* with forty-eight additional stars whose variability seems certain.

* Zweiter Catalog von veränderlichen Sternen, Mannheim, 1875.

TABLE I. — *Continued.*

No.	Class.	Discoverer.	Date.	Obs. 1883.	Obs. 1880-82.
122	II.?	Baxendell	1859	10 C.	Sm.
123	II.	Hencke	1859	7 C. 24 H.	W.
124	I.	Janson	1600	—	—
125	II.	Knott	1871	8 C. 10 P.	Bm. Sf. W.
126	II.?	Pogson	1856	8 C.	Sf.
127	II.	Birmingham	1881	8 C.	Bm. K. Sf. Sm.
127*a*	II.	Baxendell	1860	8 C.	Sm.
128	II.	Baxendell	1863	7 C.	D. Sm.
129	II.	Pogson	1858	8 C.	—
130	—	Schmidt	1864	—	—
131	II.	Goldschmidt	1861	8 C.	Sm. W.
132	II.	At Bonn	1858	15 C.	W.
132*a*	—	Peters	1867	—	—
132*b*	II.?	Ceraski	1878	6 C.	H. Knott, Sm.
133	II.	Hind	1854	11 C.	—
134	II.	Hencke	1858	7 C.	Sf. W.
134*a*	I.	Schmidt	1876	—	—
135	III.?	Hind	1848	—	D.
136	II.	Hind	1863	6 C. 18 P.	Sm.
137	IV.	Goodricke	1784	—	Sm. W.
137*a*	—	Deichmüller	1883	11 C.	—
138	II.	Argelander	1853	5 C.	—
139	III.	Schmidt	1847	—	Sm.
140	II.	Hind	1848	6 C.	Sm.
141	II.	Marth	1864?	6 C.	—
142	II.	Harding	1811	8 C.	Sm.
143	II.	Pogson	1853	11 C. 26 P.	Sm.

The first column of the left-hand page of Table I. gives a provisional number for designating the star. This number is taken from Schönfeld's Catalogue when the star occurs there; in other cases, a letter is added to the number. Other letters may be employed in effecting additional interpolations. The second column contains numbers from the catalogue of stars observed with the meridian photometer at the Harvard College Observatory, to be printed in Volume XIV. of the Annals of that institution. The letters H. P. (Harvard Photometry), prefixed to a number, will denote a reference to this catalogue. The following columns contain the right ascension and declination of the star for 1875, its magnitude at maximum and minimum, and its period in days.

The first column of the right-hand page repeats the number to be used for the provisional designation of the star. The second gives the class to which the star belongs, upon the system of classification employed in the Proceedings of the American Academy of Arts and Sciences, XVI. 257. Upon this system, Class I. includes tem-

porary stars; Class II., stars undergoing large variations in periods of several months; Class III., irregularly variable stars undergoing but slight changes in brightness; Class IV., variable stars of short period, like *β Lyræ* or *δ Cephei;* Class V., Algol stars, or those which at regular intervals undergo sudden diminutions of light, lasting for but a few hours. The third column gives the name of the discoverer, and the fourth column the date. The fifth column gives the number of nights on which each star was observed in 1883 by the observers, whose initials are appended to the figures. These initials are placed in alphabetical order, and are explained below. The last column contains the names of other astronomers who are known to have observed the corresponding stars since 1880. Some of these names have been abbreviated as follows: Dunér, D.; Hartwig, H.; Safarik, Sf.; Schmidt, Sm.; Wilsing, W.

The initials in the last column but one of Table I. refer to the following series of observations: —

C. This series is carried on by Mr. S. C. Chandler, Jr., at the Harvard College Observatory. The telescope employed was made by Mr. Clacey. Its aperture is 6¼ inches, and the magnifying power employed is generally 45; sometimes, 125 or 200. The observations were begun in March, 1883, but their number has been greatly increased since October. The present plan contemplates two or three observations of each variable belonging to Class II. during every month, whenever it is sufficiently bright to be visible. The observations are made by Argelander's method. Estimates of magnitude are also made independently.

H. These observations are made by the Rev. J. Hagen, S. J., at Prairie du Chien, Wisconsin. After the middle of November, 1883, the observations were independently repeated by Mr. Zwack. The instrument is a telescope by Merz, three inches in aperture. The observations are made by the division into tenths of the interval between two comparison stars. A copy of all the observations has been received at the Harvard College Observatory, and is available for the discussion of the variations of any of the stars observed.

L. These observations were made by Mr. H. A. Lawrence, and will be mentioned below, under the heading U.

P. These observations are made by Mr. H. M. Parkhurst, at Brooklyn, N. Y., with a telescope made by Fitz, nine inches in aperture. The magnifying powers employed are 56 and 150. Many of the observations are made by Argelander's method, and the remainder with photometric apparatus devised by Mr. Parkhurst, in

order to effect an optical diminution of the aperture, without diminishing the brightness of the field, until the disappearance of the star. The telescope being fixed, the pencil of rays is gradually intercepted and slightly deflected by a prism, the proportion of the light being determined by the time which elapses after the passage of the transit wire by the star. Both accuracy and facility of reduction are much increased by placing over the object-glass caps bounded by logarithmic curves. A copy of the observations has been received at the Harvard College Observatory, and is available for the discussion of the variations of any of the stars observed.

S. These observations are made by Mr. E. F. Sawyer, at Cambridgeport, Mass., by means of an opera-glass for the brighter stars, and of a field-glass for the others. It is to be noticed that the observations of the star 95 *b*, made by Mr. Sawyer on twelve nights, consist in the observation of twelve minima, each series usually including a large number of comparisons. Mr. Sawyer has sent the results of all his observations to the *Astronomische Nachrichten.*

U. These observations were made by Professor Winslow Upton, of Brown University, during an expedition to observe the total eclipse of the Sun which occurred on May 6, 1863. The observations were chiefly made on board the U. S. S. Hartford, but partly on Caroline Island, in the Pacific Ocean. No instruments except a field-glass were employed in the comparisons, which were made by the division into tenths of the interval between two comparison stars. Most of the observations were independently repeated by Mr. H. A. Lawrence. The stars observed were all south of —30° declination; no account has been received of any other observations of these southern stars during 1883.

Z. These observations were made by Mr. Zwack, and have already been mentioned under the heading H.

Although it is of course impossible to prepare a complete list of stars suspected of variability, as distinguished both from known variables and from stars about the magnitude of which observers have slightly differed, the attempt has been made in Table II. to provide a list of stars for the variability of which there is evidence enough to make them interesting objects. When the variability of any of these stars has been fully established, it will be very desirable to determine their maxima, minima, periods, and light curves. In observing these objects, the comparisons should be made either by Argelander's method or by some other of sufficient precision to decide the question of variability. The mere estimation of magnitudes cannot suffice for this purpose.

TABLE II. — Suspected Variables.

No.	H. P.	R. A. 1875. h.	m.	s.	Dec. 1875. °	′	Max.	Min.	Authority.
1	23	0	6	49	+14	29.7	2.5	3.1	Schwab
5	—		17	27	—10	9.1	10	—	Borelly
9	—		37	51	+ 6	36.9	9	12	Hind
25	—	1	15	0	+ 9	1.6	10	Inv.	Tempel
47	—		47	45	+ 8	9.9	6.7	8	Argelander
49	—		49	25	—68	33.6	6.6	7.5	Gould
59	—	2	10	24	+58	22.3	8.5	9.5	Safarik
73	—	3	37	37	+ 9	0.2	9½	Inv.	Palisa
75	—		38	1	+23	41	—	—	Wolff
81	—		46	29	+ 7	24.1	6¾	8	Gould
87	—		57	46	+28	38.4	9.5	12	Kreutz
93	—	4	14	32	+19	31.1	9.2	10.0	Baxendell
97	—		32	28	+13	28.5	9.5	Inv.	Palisa
103	867		49	42	—16	37.2	5.4	6.0	Gould
111	881		53	57	+ 3	25.8	6	6¼	Gould
113	883		54	7	—12	43.4	4.8	5.7	Gould
139	—	5	23	49	— 1	7.7	9	—	Argelander
143	—		27	23	+21	51.5	8½	11½	Schmidt
145	1018		28	18	+10	9.6	5.7	6.7	Gould
147	1021		28	56	— 6	5.5	5	6	Falb & Gould
161	—	6	11	14	— 1	31.6	8	9½	Copeland
167	—		59	22	+23	5.9	9.0	12	Safarik
189	—	7	36	2	—31	22.3	6.5	7.4	Gould
195	—		43	52	—40	20.6	6.5	7.2	Gould
201	—		59	44	+23	8.7	9.5	—	Palisa
205	—	8	2	26	+19	48.3	9.7	14	Peters
209	—		21	8	+ 9	0	9½	—	Palisa
227	1684	9	13	13	—23	57	6	8½	Schönfeld
239	—		27	25	—56	29.0	3½	4½	Gould
251	—		44	32	+30	41.7	9	Inv.	Schmidt
259	—	10	1	27	—51	34.8	6½	7½	Gould
269	—		12	55	+ 7	49.8	9½	—	Palisa
271	—		12	55	—60	42.5	3.3	4.5	Gould
277	—		21	55	—73	23.7	4.2	5.1	Gould
293	—		45	33	—20	35.2	6	8	Gould
294	—		47	2	+14	22.9	9	—	Peters
311	—	12	7	31	+ 0	16.8	8	8.7	Harrington
337	—		32	41	+17	11.8	8.8	10.0	Weiss
339	—		32	54	+17	10.7	—	—	Weiss
345	2160		37	2	—13	10.4	5	7	Schönfeld
347	2164		39	15	+46	7.4	6	—	Schmidt
365	2293	13	28	2	—12	35.1	5.7	6.3	Schmidt
373	2343		43	27	+16	25.1	—	—	Schmidt
375	—		47	47	+11	41.1	8½	—	Hind
381	—		56	25	— 1	46.6	8	9	Copeland
383	—		58	15	— 8	35.9	11	—	Peters
405	—	14	39	59	—56	8.3	6	7	Gould
407	2475		42	41	+ 6	28.9	6	8	Hussey
411	—		43	42	—76	9.0	5.5	6.2	Gould
421	—		58	9	—68	14.2	7.0	7.4	Gould
433	—	15	26	53	—48	55.8	7	9½	Gould
437	—		28	59	—20	45.0	—	—	Peters
441	—		30	47	—15	45.5	—	—	Peters

TABLE II. — *Continued.*

No.	H. P.	R. A. 1875. h.	m.	s.	Dec. 1875. °	′	Max.	Min.	Authority.
447	—	15	36	28	—10	31.1	7.0	6.8	Weiss
449	—		38	46	—34	17.3	5½	6½	Gould
451	—		39	14	—20	44.3	11	Inv.	Peters
453	—		43	23	+28	40.0	11	12½	Schmidt
459	—	16	1	11	—21	11.4	11	< 13	Peters
471	—		22	22	—19	14	—	Inv.	Peters
475	—		30	47	+ 7	22.1	7	8	Chandler
483	—		44	45	— 5	57.6	8	11	Birmingham
509	3048	18	2	43	+28	44	4½	—	Schwab
511	—		9	19	—34	8.8	6.2	7.4	Gould
513	—		9	49	+71	3.1	9	—	Schmidt
517	—		27	58	+36	53.9	7½	9	Birmingham
531	—		53	32	—37	8.3	10	—	Schmidt
547	3362	19	25	40	+27	41.9	3.3	3.9	Klein
549	—		27	9	+17	28.5	6½	9½	Nature
555	—		35	19	+12	52.9	6½	9½	Argelander
557	—		37	57	+35	55.2	8½	10	Argelander
567	—	20	7	8	—22	21.4	11	— ?	Peters
601	—	21	1	24	—21	51.3	11½	Inv.	Peters
609	—		12	42	—50	27.6	6.1	7.3	Gould
615	—		56	30	—17	13.7	11	14 ?	Peters
625	3977	22	23	57	—26	42.7	5½	6.7	Schmidt
635	—	23	14	51	+55	25.8	8.2	8.8	Argelander
651	—		51	30	— 9	39.4	9.7	14 ?	Peters

The list given in Table II. is extracted from Mr. Chandler's unpublished catalogue of suspected variables, and comprises the objects in that catalogue the variability of which is suspected on reasonably good evidence. The first column contains the provisional numbers by which the corresponding stars are designated in Mr. Chandler's catalogue. The second column, as in Table I., gives the H. P. number. The remaining columns contain the right ascension and declination for 1875, the supposed magnitude at maximum and at minimum, and the authority for the suspicion of variability.

Accurate observations of these stars, or of other similar objects, are much to be desired. Information respecting the dates of observation, and results derived from the comparisons, which may be communicated by observers, will be published in the circular for 1885, whether they relate to 1884 or to previous years.

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XIII.

THE PHASES OF THE MOON.

By Arthur Searle.

Presented April 9, 1884.

During the passage of the Moon through the ordinary course of its phases, the observed variations of the total amount of light which we receive from it are not readily accounted for by the accepted laws of optics. The *Photometrische Untersuchungen* of Zöllner (Leipzig, 1865) contains the results of previous inquiries into this subject, including those of Zöllner himself. Since then, so far as I have learned, no important observations or theories relating to the phases of the Moon have been made public. Additional knowledge of these phases would have some useful applications to other subjects, and in particular to that theory of the zodiacal light which ascribes it to sunlight reflected from meteoric matter. From this point of view, an examination of Zöllner's conclusions in the work above named, and an attempt to derive some additional inferences from the material collected by him, may be desirable.

The formula most commonly assumed as an expression of the variation of the total observed light of a distant object, in consequence of its changes of phase, is due to Lambert. The hypothesis on which it depends is that the light received from equally bright surfaces will be proportional to their apparent areas. In other words, Lambert asserts the quantity of light received from a small distant object to be proportional, other things being equal, to the magnitude of its orthographic projection upon a plane perpendicular to the line of sight. The validity of the assertion was rather feebly supported by Lambert himself, and has never been clearly established. Zöllner, however, has pointed out some considerations favorable to Lambert's hypothesis; and it will probably continue to find employment, in the want of a more complete investigation of the question to which it relates.

In addition to this special hypothesis, Lambert accepts the ordinary photometric rule, (which appears to be almost a necessary consequence of the rectilinear transmission of light,) that the actual illumination of

a small surface, at a great distance from the source of light, will be proportional to the magnitude of its orthographic projection upon a plane perpendicular to the incident rays; that is, if the surface is plane, to the cosine of the angle of incidence. Its apparent illumination, then, upon Lambert's theory, will be proportional, at any single point, to the product of the cosines of the angles of incidence and emanation at that point, if we understand the angle of emanation to signify the angle between the normal to the illuminated surface and its direction from the observer. This theory assumes that the reflection of light from the given surface takes place irregularly, specular reflection being altogether neglected. For this reason, as well as for others stated by Zöllner (p. 24), Lambert's formula seems likely to be fully applicable only to somewhat translucent objects. A strictly opaque object, if smooth, will probably exhibit the phenomena of specular reflection to such an extent as to destroy the value of the formula; if rough, the theoretical quantity of irregularly reflected light will be variously reduced in different phases by the shadows of the prominences.

With the assumptions above explained, Lambert arrived at the result that the light received by irregular reflection from a distant sphere would vary with the phases of the sphere in accordance with the expression $\sin v - v \cos v$, where v denotes the angular magnitude of the phase. It may also be defined as the exterior angle, at the illuminated object, of the triangle formed by the straight lines connecting that object, the source of light, and the observer. If the total quantity of light received from the sphere when in exact opposition is regarded as unity, the quantity in any other phase will accordingly be denoted by $\frac{1}{\pi}(\sin v - v \cos v)$, provided that we regard as constant quantities the intensity and magnitude of the source of light, the magnitude and reflecting power of the sphere which it illuminates, and the distance of the sphere both from the source of light and from the observer. The coefficients depending upon these quantities will accordingly be neglected in the present inquiry.

Zöllner, in order to simplify the discussion of the lunar phases, shows that the variable factor $\sin v - v \cos v$ will be applicable, on Lambert's hypothesis, to the phases of a right cylinder, with its axis perpendicular to the plane of the triangle having its vertices at the source of light, the cylinder, and the observer. The proposition may apparently be extended to any surface of revolution subjected to the same condition. Let dl denote an element of the generating line, dh its orthographic projection on the axis, and dp its orthographic

projection on a fixed plane containing the axis. Let r denote the perpendicular let fall upon the axis from dl, and θ the angle made by r with a perpendicular to the fixed plane. The arc described by a point in dl during the small fraction of a revolution which may be denoted by $d\theta$ is expressed by $rd\theta$; the projection of this arc upon the fixed plane is $r \cos \theta \, d\theta$. The projection of the surface, having dl and $rd\theta$ for its altitude and base, has $r \cos \theta \, d\theta$ for its base, but dh, not dp, for its altitude. Accordingly, if l denotes the entire length of the generating line, and h its projection on the axis, the ratio of the element, described by the generating line during its movement through $d\theta$, to its projection on the fixed plane, is expressed by $\frac{l}{h \cos \theta}$. Hence, for different values of θ, the projections of the corresponding elements of the surface are proportional to $\cos \theta$. If the projection of each of the surfaces described by the elements of l during its movement through $d\theta$ is substituted for that surface, and again orthographically projected upon a new plane containing the axis, the final projections of corresponding elements of the surface will appear by the same course of reasoning to be proportional to $\cos \theta \cos \gamma$, where γ denotes the angle made by r with the perpendicular to the new plane. We may regard θ as the angle of incidence of parallel rays of light upon a cylinder circumscribing the supposed surface, and having the same axis; γ may be regarded as the corresponding angle of emanation. On Lambert's hypothesis, the ratio of light received from the given surface in different phases will be the ratio of quantities obtained by the integration of $\cos \theta \cos \gamma \, d\theta$ between limits determined for each phase by the extent of the illuminated surface. Denoting the magnitude of the phase, as above, by v, and regarding θ and γ as positive when they are measured from the normal towards the terminator, the limiting values of θ are $-\frac{1}{2}\pi$ at the terminator, and $-(\frac{1}{2}\pi - v)$ at the illuminated limb; those of γ are $\frac{1}{2}\pi - v$ at the terminator, and $\frac{1}{2}\pi$ at the illuminated limb. For any value of γ, the corresponding value of θ is $\gamma - (\pi - v)$. Hence $\cos \theta \cos \gamma \, d\theta = -\cos \gamma \cos (v + \gamma) \, d\gamma$, the indefinite integral of which is $-\frac{1}{2}[\sin \gamma \cos (v + \gamma) + \gamma \cos v]$. Integrating between the given limits of γ, we have the result $\frac{1}{2}(\sin v - v \cos v)$; the constant factor $\frac{1}{2}$ indicates limitation to half the surface, and vanishes from the ratio between the quantities of light received from different phases. The integration may be somewhat simplified by employing the mean of θ and γ as the variable, with the aid of the general formula

$$\sin (a + b) \sin (a - b) = \frac{1}{2} (\cos 2b - \cos 2a).$$

To find the ratio of light, for a given phase, between two different surfaces of revolution, we have only to determine the corresponding ratio of light for single elements of each surface, with the same values of θ and of γ for each element; the values to be assumed in practice are $\theta = \gamma = 0$. In the case of the sphere and the circumscribing cylinder, the height of which is equal to the diameter of the sphere, let ζ denote the angle between the axis and the radius drawn to any point in that element of the sphere for which θ and γ vanish. At this point, the angles of incidence and emanation are each equal to the complement of ζ; and the quantity of light received from the immediate vicinity of the point will have the ratio $\sin^2 \zeta$ to that received from an equal surface at any point of the corresponding element of the cylinder. But as the width of the spherical element, at the given point, is the product by $\sin \zeta$ of the width of the cylindrical element, the quantity of light received from the element of the sphere, at the given point, will have the ratio $\sin^3 \zeta$ to that received from an equal length of the element of the cylinder. Accordingly, if the radius of the sphere is the unit of length, the ratio of the quantities of light received from the spherical and cylindrical elements is $\frac{1}{2} \int_0^\pi \sin^3 \zeta \, d\zeta$. Changing the variable to $-\cos \zeta$, which we may represent by x, we have

$$\tfrac{1}{2} \int_0^\pi \sin^3 \zeta \, d\zeta = \tfrac{1}{2} \int_{-1}^{+1} (1 - x^2) \, dx = \tfrac{2}{3},$$

the ratio found by Zöllner (p. 40), from an independent determination of the phases of the cylinder, combined with Lambert's similar proposition relating to the sphere. It is also sufficiently apparent, although not distinctly set forth, in Seidel's statement of Lambert's demonstration, that this ratio exists.

If, instead of the sphere, we consider a right cone, inscribed in a cylinder of the same height and base, the coefficient required to reduce the phases of the cylinder to those of the cone is readily perceived to be $\frac{1}{2} \cos \chi$, in which χ denotes the inclination of the generating straight line to the axis. The direct determination of the phases of the cone is nearly as simple. The cosines of the angles of incidence and emanation will be respectively expressed by $\cos \chi \cos \theta$ and $\cos \chi \cos \gamma$; the slant height of the cone is proportional to $\sec \chi$; and the expression to be integrated becomes

$$- \tfrac{1}{2} \cos \chi \cos \gamma \cos (v + \gamma) \, d\gamma.$$

For a frustum the height of which is insignificant in comparison with the total height of the cone, the coefficient $\frac{1}{2}$ disappears.

Zöllner regarded the analogy existing between the phases of a smooth cylinder and a smooth sphere as an indication that the effect of roughening the surfaces would be somewhat similar in the two cases (p. 51). Although it is doubtful if this extension of the analogy can be carried far, it is still reasonable to think that it may be of use in obtaining some notion of the kind of modification which Lambert's formula will require when it is applied to the phases of a mountainous body like the Moon. Zöllner accordingly considered the consequences of covering the surfaces of the cylinder with furrows parallel to the axis, and obtained a general expression for the phases of this furrowed cylinder without regarding the dimensions of the furrows as insignificant with respect to the diameter of the cylinder. By so regarding them, the expression was afterwards reduced to

$$\sin(v-\beta)-(v-\beta)\cos(v-\beta),$$

if we omit, as before, various factors independent of the phase. In this expression, β signifies the angle between the base and the slope of each ridge, called by Zöllner the angle of elevation. He found his own photometric observations between half and full moon well satisfied by this formula when the value of β was assumed to be 52°.

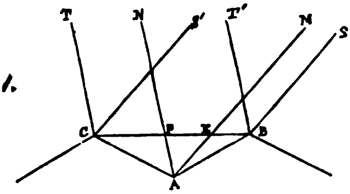
The geometrical significance of the expression

$$\sin(v-\beta)-(v-\beta)\cos(v-\beta)$$

was partially developed by Zöllner (p. 66). A sufficient extension of the process would have enabled him to correct an error in his analysis which, as it happened, did not attract his attention. The expressions for the elementary surfaces F_1 and F_2 (pp. 55 and 56) are not applicable throughout a sufficiently large phase. Both the general expression and the simplified formula above mentioned are therefore incomplete. The correction of the general expression is unnecessary for our present purpose. We may accordingly regard a section of the cylinder perpendicular to its axis as a regularly serrated circle, each serration being so small that the arc forming its base must be considered as a straight line.

In the following figure, let A represent the junction of two adjacent serrations, the vertices of which are at B and C. From B and C draw the parallels BS, CS′, directed towards the source of light, and BT′, CT, directed towards the observer. From A draw AM parallel

Fig. 1.



to BS, and AN parallel to CT, respectively intersecting the straight line BC at E and F.

Upon Lambert's hypothesis, equal amounts of light will emanate from all straight lines at a sufficient distance from the observer, intercepted between the parallels AN, BT′, and equally illuminated; that is, so illuminated that equal lengths of different lines receive equal quantities of incident light. This condition will be fulfilled (if the intensity of the illumination remains the same for all the lines) when the lines make equal angles with the rays of light. Suppose the furrowed cylinder to be inscribed in a smooth cylinder, and BC to represent a sensibly straight portion of the circle bounding the intersection of the new cylinder with the plane containing the lines AB, AC. At the same time, let the system of lines directed to the source of light be revolved about B as a centre through the angle ABC, so that the inclination of BS to BC may become equal to the former inclination of BS to BA. The illumination of the line BC, or of any part of it, as BF, will now be equal to the former illumination of BA. But BF and BA are both intercepted between the parallels AN, BT′; hence the quantity of light emanating from BF is equal to that formerly emanating from BA. The revolution of BS about B has increased the angle SBT′ by the amount ABC; but SBT′ is the supplement of the magnitude of the phase, and ABC is equal to the angle of elevation of the serrations. Accordingly, when the phase of the smooth cylinder is less than the phase of the furrowed cylinder by an amount equal to this angle of elevation, equal quantities of light will reach the observer from the surfaces of which BF and BA are respectively the sections.

If the position of the observer is changed, so that the angle CBT′ becomes equal to the angle of elevation ABC or ACB, the point F coincides with C; in this case, equal quantities of light are received from BC in the smaller, and from BA in the greater phase. For still smaller values of CBT′, we have merely to substitute for BA that part of it still visible to the observer. Hence, while the phase remains so small that no pair of adjacent slopes, like AB and AC, are at once

illuminated and visible, the light received from the visible parts of slopes facing towards the terminator is equal to that received from the continuous surface of the same region of the smooth cylinder when the phase is diminished by an amount equal to the angle of elevation. In this case, the formula obtained by Zöllner is partially applicable, since it is accordant with the fact that no light will be received from the furrowed cylinder until the phase is larger, by an amount equal to the angle of elevation, than the initial phase of the smooth cylinder. As this was the only point considered in Zöllner's geometrical interpretation of his formula, the result of his analysis appeared to be confirmed.

In considering the quantities of light received from the slopes facing the illuminated limb, it will be convenient to assume what is approximately true in the case of the Moon, that during the changes of phase the angles of emanation at given points of the illuminated surface are constant. Upon Lambert's hypothesis, equal quantities of light will emanate from lines equally inclined to the line of sight, but of different lengths, provided that these lines have received equal quantities of incident light. In the figure, the lines CA, CE, receive equal quantities of incident light, and if we now suppose the phase diminished by the revolution of CT, and the lines parallel to it, about C as a centre, through the angle ACB, the observed light from CE will be equal to the light formerly received from CA. Since, however, we have assumed the direction of CT with respect to CA to be invariable, this result signifies that, when the phase is diminished, a quantity of light equal to that formerly received from CA is now received, not from CE, but from an equal arc of the circumference of which CE is part, situated as far from the new terminator as CE was from the original terminator. It may also be observed that BF + CE > BC. Hence, in order to assume, with Zöllner, that the light received from the smooth cylinder in the reduced phase is equal to that previously received from the furrowed cylinder, we must assume at the same time an increase of reflecting power in part of the smooth cylinder. Leaving other geometrical considerations to suggest themselves, we may now construct the formula required to represent the phases of the furrowed cylinder.

Returning to the figure, let s denote the length of the slope AB or AC; β, the angle of elevation ABC or ACB; $\pi - v$, the supplement SBT′ of the magnitude of the phase; θ, the angle of incidence on BC, of which MEB is the complement; and γ, the corresponding angle of emanation, the complement of which is NFC. As before, θ and γ will be regarded as positive when measured from the normal to BC towards

the terminator, and the constant factors expressing the intensity of the light and the dimensions of the cylinder will be neglected. The short arc BC may be represented by $d\gamma$, if we consider the vertex of an angle equal to γ as placed in the axis of the cylinder. The quantities of light received from the slopes AB and AC will be respectively expressed by $s \cos(\theta - \beta) \cos(\gamma - \beta)$ and $s \cos(\theta + \beta) \cos(\gamma + \beta)$. The value of s is $\frac{1}{2} \sec \beta \, d\gamma$, and that of θ is $\gamma - (\pi - v)$.

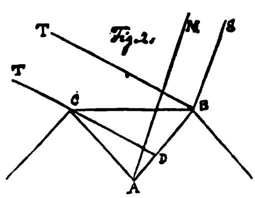
These expressions do not represent the consequences which result from the opacity of the surfaces considered, so that the integration must be confined to the limits within which the whole surface of every slope is illuminated and visible. The slopes facing towards the terminator for which $\theta - \beta < -\frac{1}{2}\pi$ will not be illuminated, and the slopes respectively opposite them will be partly in the shade. The slopes facing towards the illuminated limb for which $\gamma + \beta > \frac{1}{2}\pi$ will not be visible, and those opposite to them will be partly hidden. The required integral is therefore

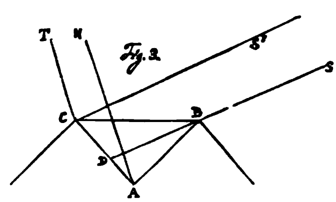
$$-\tfrac{1}{2} \sec \beta \left[\int_{\frac{1}{2}\pi - v}^{\frac{1}{2}\pi - 2\beta} \cos(\gamma - \beta) \cos[v + (\gamma - \beta)] \, d(\gamma - \beta) + \int_{\frac{1}{2}\pi - v + 2\beta}^{\frac{1}{2}\pi} \cos(\gamma + \beta) \cos[v + (\gamma + \beta)] \, d(\gamma + \beta) \right]$$

the terms of which have the same form as that of an expression already found (p. 312). If $v = 2\beta$, as well as when $v < 2\beta$, no finite region exhibits slopes wholly visible and illuminated, so that this formula is then inapplicable. For those cases in which $v > 2\beta$, the sum of its two equal terms becomes, on reduction,

$$\tfrac{1}{2} \sec \beta \, [\cos 2\beta \sin(v - 2\beta) - (v - 2\beta) \cos v].$$

When $\beta = 0$, the limits of the integration coincide with those of the phase, and the result becomes $\frac{1}{2}(\sin v - v \cos v)$, as before. When $\beta = \frac{1}{2}\pi$, v cannot exceed 2β.





To complete the solution, we have still to consider the partly visible and the partly illuminated slopes. The first case is exhibited in Fig. 2,

and the second in Fig. 3. The length of BD, the visible portion of the slope AB, is readily found to be $\frac{\cos\gamma}{\cos(\gamma-\beta)}\,d\gamma$; that of CD, the illuminated portion of AC, is $\frac{\cos\theta}{\cos(\theta+\beta)}\,d\gamma$. The expressions to be integrated in the two cases are respectively $\cos\gamma\cos(\theta-\beta)\,d\gamma$, and $\cos\theta\cos(\gamma+\beta)\,d\gamma$. The first may be reduced to

$$-\cos\gamma\cos[(v-\beta)+\gamma]\,d\gamma;$$

the second to

$$-\cos(v+\gamma)\cos(\gamma+\beta)\,d\gamma,$$

and this, again, to

$$-\cos(\gamma+\beta)\cos[(v-\beta)+(\gamma+\beta)]\,d(\gamma+\beta).$$

To determine the limits of integration, we are to consider that while $v<\beta$ no illuminated portion of the furrowed cylinder can be visible; and also that for values of v between β and 2β two illuminated portions of the cylinder will be visible, separated by a dark interval. Part of each slope facing towards the terminator will be illuminated, and will include a visible portion, for values of γ extending from $\frac{1}{2}\pi$ to $\frac{1}{2}\pi-(v-\beta)$. These are accordingly the limiting values of γ in the integration of $-\cos\gamma\cos[(v-\beta)+\gamma]\,d\gamma$. Part of each slope facing towards the illuminated limb will be visible, and will include an illuminated portion, for values of γ extending from $\frac{1}{2}\pi-\beta$ to $\frac{1}{2}\pi-v$, where the terminator is reached. The expression

$$-\cos(\gamma+\beta)\cos[(v-\beta)+(\gamma+\beta)]\,d(\gamma+\beta)$$

is consequently to be integrated between the limits

$$\tfrac{1}{2}\pi \quad\text{and}\quad \tfrac{1}{2}\pi-(v-\beta).$$

It is only necessary to compare these expressions, and their limits, with the results obtained above (p. 312), to see that each of the definite integrals required will have the value

$$\tfrac{1}{2}[\sin(v-\beta)-(v-\beta)\cos(v-\beta)];$$

it is also apparent from geometrical considerations that this should be the result for values of v between β and 2β. When $v>2\beta$, the inferior limit of the integration of $-\cos\gamma\cos[(v-\beta)+\gamma]\,d\gamma$ remains constant at $\frac{1}{2}\pi-\beta$; and the superior limit of the other integration becomes $\frac{1}{2}\pi-(v-2\beta)$. The result of each integration is now

$$\tfrac{1}{2}[\sin\beta\cos(v-2\beta)-\beta\cos(v-\beta)].$$

When $v = 2\beta$, this result coincides, as it should, with that from

$$\tfrac{1}{2}\left[\sin(v-\beta) - (v-\beta)\cos(v-\beta)\right].$$

The collection of the separate results of the inquiry furnishes the following rule for computing, upon Lambert's hypothesis, the phases of a right cylinder, with a surface occupied by regular furrows, parallel to the axis, and of dimensions too small to be comparable to those of the cylinder, which is supposed to be placed at a great and constant distance from the source of light and also from the observer, with its axis perpendicular to the rays of incident light and to the line of sight: —

If we adopt as the unit of measurement the quantity of light received from a smooth cylinder equal in height and diameter to the furrowed cylinder, when the magnitude of the phase is an entire semi-circumference, denoting this magnitude, for any phase, by v; the angle of elevation, formed by the base and slope of each ridge, by β; and the observed quantity of light, by L; then, if $\beta = 0$,

$$L = \frac{1}{\pi}(\sin v - v\cos v). \qquad (1)$$

If $\beta > 0$, and $v < \beta$, $L = 0$.

If $v > \beta > 0$, and $v < 2\beta$,

$$L = \frac{2}{\pi}\left[\sin(v-\beta) - (v-\beta)\cos(v-\beta)\right]. \qquad (2)$$

If $v = 2\beta$,

$$L = \frac{2}{\pi}(\sin\beta - \beta\cos\beta). \qquad (3)$$

If $v > 2\beta > 0$,

$$L = \frac{2}{\pi}\left[\sin\beta\cos(v-2\beta) - \beta\cos(v-\beta)\right]$$
$$+ \frac{1}{\pi}\sec\beta\left[\cos 2\beta\sin(v-2\beta) - (v-2\beta)\cos v\right]. \qquad (4)$$

By the collection of the terms of equation (4) which contain respectively $\sin v$ and $\cos v$, the equation is reduced to

$$L = \frac{1}{\pi}\sec\beta\left[(1-\beta\sin 2\beta)\sin v - (v - 2\beta\sin^2\beta)\cos v\right]. \qquad (5)$$

Equation (5) is readily transformed to

$$L = \frac{1}{\pi}\sec\beta\left[\sin v - v\cos v - 2\beta\sin\beta\sin(v-\beta)\right]. \qquad (6)$$

Since the expression $\log\frac{2}{3\pi}(\sin v - v\cos v)$ has been tabulated

by Seidel,* equation (6) is somewhat better adapted to numerical computation than equation (5). Equation (2) may be very readily computed from Seidel's table.

By means of equations (2) and (6), numerical expressions may be obtained for the quantities of light corresponding to the phases of the furrowed cylinder for assumed values of β, in terms of the quantity of light received from the smooth cylinder in opposition. If we adopt as the unit the quantity of light received from the furrowed cylinder itself when $v = \pi$, we must divide each result by the corresponding value of the expression $\frac{1}{\pi} \sec \beta \, (\pi - 2 \beta \sin^2 \beta)$.

The differential coefficient of the value of L in equation (6), taken with respect to v, is

$$\frac{1}{\pi} \sec \beta \, [v \sin v - 2 \beta \sin \beta \cos (v - \beta)].$$

The value of L, accordingly, if $\beta > 0$, does not reach a maximum when $v = \pi$. For this value of v, L is greatest when the value of β is about 38°; when $\beta = 60°$, $L = 1$; and for the limiting value $\beta = 90°$, $L = \frac{2}{\pi}$. This last result appears from equation (3); equation (6) is not applicable to the case without previous reduction to (3), since v cannot exceed 2β when $\beta = \frac{1}{2} \pi$.

Numerical values of L for six assumed values of β are given in Table I. The unit of light, in this part of the table, is the quantity received from the smooth cylinder when $v = \pi$. The last three columns contain results derived from the work of Zöllner. The first of these columns contains the values of L according to his formula, when $\beta = 52°$, and when the amount of light received upon this supposition is regarded as unity if $v = \pi$. The next two columns relate to the twenty-two sets of observations, the results of which are given on page 102 of his work. These results are here arranged in accordance with the values of v, for which, the phase being always large, Zöllner substitutes the corresponding elongations of the Moon. The values of v are here printed in Italics when the observations were made after full moon. The observation made when $v = 179°$ is assumed by Zöllner to be in accordance with his formula, in order to compare the other observations with the results of the theory. This assumption is here retained.

* Untersuchungen über die Lichtstärke der Planeten Venus, Mars, Jupiter und Saturn. München, 1859. (Pp. 100–102 contain the table above mentioned.)

TABLE I.

v	Theoretical Results for Cylinder.						Zöllner's Formula.	Zöllner's Observations.	
	$\beta=0°$	$\beta=30°$	$\beta=38°$	$\beta=45°$	$\beta=60°$	$\beta=90°$	$\beta=52°$	v	Ratio.
5°	0.000	.....	.....	.....	.....	.....	.....	.....	.....
10	0.001	.....	.....	.....	.....	.....	.....	.....	.....
15	0.002	.....	.....	.....	.....	.....	.....	.....	.....
20	0.004	.....	.....	.....	.....	.....	.....	.....	.....
25	0.009	.....	.....	.....	.....	.....	.....	.....	.....
30	0.015	.....	.....	.....	.....	.....	.....	.....	.....
35	0.023	0.000	.....	.....	.....	.....	.....	.....	.....
40	0.034	0.001	0.000	.....	.....	.....	.....	.....	.....
45	0.048	0.004	0.000	.....	.....	.....	.....	.....	.....
50	0.065	0.009	0.002	0.000	.....	.....	.....	.....	.....
55	0.085	0.017	0.005	0.001	.....	.....	0.000	.....	.....
60	0.109	0.030	0.012	0.004	.....	.....	0.000	.....	.....
65	0.136	0.047	0.022	0.009	0.000	.....	0.002	.....	.....
70	0.166	0.068	0.036	0.017	0.001	.....	0.005	.....	.....
75	0.200	0.094	0.055	0.030	0.004	.....	0.010	110	0.208
80	0.236	0.125	0.079	0.047	0.009	.....	0.018	*111*	0.146
85	0.276	0.161	0.109	0.069	0.017	.....	0.028	*118*	0.204
90	0.318	0.201	0.144	0.097	0.030	.....	0.043	122	0.271
95	0.363	0.245	0.186	0.180	0.047	0.000	0.062	*128*	0.291
100	0.410	0.293	0.228	0.170	0.069	0.001	0.084	134	0.361
105	0.458	0.343	0.278	0.215	0.097	0.004	0.112	*138*	0.381
110	0.508	0.397	0.330	0.265	0.131	0.009	0.144	189	0.439
115	0.558	0.453	0.387	0.320	0.171	0.017	0.181	140	0.471
120	0.609	0.511	0.447	0.378	0.218	0.080	0.228	*141*	0.417
125	0.659	0.569	0.507	0.440	0.271	0.047	0.270	147	0.486
130	0.708	0.628	0.569	0.503	0.331	0.069	0.821	*152*	0.570
135	0.755	0.686	0.631	0.568	0.395	0.097	0.377	152	0.562
140	0.800	0.743	0.693	0.634	0.464	0.131	0.437	153	0.635
145	0.842	0.798	0.754	0.699	0.535	0.171	0.501	*153*	0.579
150	0.881	0.850	0.812	0.763	0.607	0.218	0.568	156	0.714
155	0.915	0.902	0.867	0.824	0.680	0.272	0.637	161	0.684
160	0.944	0.943	0.918	0.882	0.751	0.332	0.709	*167*	0.826
165	0.968	0.981	0.965	0.936	0.820	0.399	0.782	169	0.888
170	0.985	1.014	1.005	0.984	0.886	0.478	0.855	172	0.922
175	0.996	1.040	1.039	1.026	0.946	0.552	0.928	*175*	0.872
180	1.000	1.058	1.066	1.061	1.000	0.637	1.000	179	0.986

It is apparent upon inspection of the table, and will become still more obvious upon a graphical arrangement of the data, that β must be as large as 60° in order to represent Zöllner's observations of the Moon by means of our equation (6). For this value of β we have $L = 1$ when $v = \pi$, so that the comparison can be made at once in Table I. without any change of scale. A somewhat greater value of β would perhaps better represent the observations, but this point does not seem to require close examination. In any case, the changed form of the curve representing the successive values of L, as v increases,

renders it less accordant than Zöllner's own formula with the results of his observations. Upon examining the residuals, I find the results to be as follows:—

	Sum of Positive Residuals.	Sum of Negative Residuals.	Average Deviation.
By Zöllner's formula,	0.326	0.314	0.029
By equations (2) and (6), when $v = 60°$,	0.166	0.648	0.037
By assuming L to increase 0.137 for an increase of 10° in v,	0.518	0.431	0.043

It appears, then, that Zöllner's formula probably represents the actual phases of the Moon, near opposition, better than it represents the phases of a furrowed cylinder, computed upon Lambert's hypothesis. The similarity between the two objects is certainly not great enough to make it at all surprising that their phases should differ.

It may now be asked whether any useful inference can be derived from the theoretical investigation undertaken by Zöllner, and re-examined in the preceding pages. Before deciding this question in the negative, it may be well to review the facts which have hitherto come separately to our notice.

In the first place, while Lambert's hypothesis of the emanation of light stands greatly in need of experimental verification, it is still too accordant with some familiar facts to be regarded as a mere conjecture. Smooth rounded surfaces under a diffused illumination (as, for example, drifts of snow under a cloudy sky) have a general appearance of uniform brightness, which makes it difficult to distinguish their outlines against a background of the same color. It may well be that the true law of the emanation of light is not so simple as Lambert regarded it, while yet his hypothesis may furnish a tolerable approximation to the truth. The corresponding hypothesis with regard to incident light is so universally accepted, that it needs no verbal support, although additional experimental evidence with regard to it, and especially with regard to the modifications which it may need in practice, is highly desirable.

Accepting these two hypotheses, Lambert's formula for the phases of a smooth distant sphere follows as a matter of course; and the attempt has been made above to show that any smooth surface of revolution, with its axis perpendicular to the plane determined by the positions of the source of light, the illuminated body, and the observer, will resemble the sphere in its phases. It is therefore somewhat surprising to find that the actual phases of the Moon, at least near opposition, disagree so decidedly with the results of Lambert's formula.

Herschel's observations, as collected and reduced by Zöllner, exhibit a still greater divergence from Lambert's formula than those of Zöllner himself. Bond also obtained a like result from his own photometric observations.

It seems, accordingly, to be well worth while to investigate the results of Lambert's hypothesis when applied to a rough body of some kind. As a first step in this direction, Zöllner's discussion of the phases of a roughened cylinder was apparently judicious, although he seems to have laid too much stress on the analogy between a smooth cylinder and a smooth sphere. But the accidental error in his analysis, which has been noticed above, would have made it difficult to decide, in the absence of further examination, whether any confidence could be placed in his conclusion. The formula obtained in the preceding pages, however, agrees with Zöllner's in its most important peculiarity. We find that the phases of a furrowed cylinder, like the observed phases of the Moon, must exhibit a comparatively rapid increase of light towards opposition, and that this increase ends abruptly when opposition is reached, beginning to diminish abruptly as soon as opposition is passed. The great angle of elevation required in the ridges of the cylinder, before its computed phases begin to resemble those of the Moon, makes it probable that other forms of roughness besides that exhibited by the furrowed cylinder are concerned in the problem. But the degree of success attending the investigation proposed by Zöllner is sufficient to encourage further examination. Undoubtedly, however, additional observations are much more important, if not more interesting, than these theoretical reconciliations of Lambert's hypothesis with the facts of nature.

The meteoric theory of the zodiacal light is affected by inquiries into the phases of rough bodies, since it is highly probable that the meteors assumed to produce the light are of irregular shape and of uneven surface. An important result already obtained is, that minute but abrupt irregularities may be expected materially to modify the phases of the bodies which exhibit them, and that, upon any plausible hypothesis of reflection, such irregularities will tend to produce a relatively great amount of light in the direction opposite to that of the Sun. A few obvious remarks naturally present themselves with regard to the probable effects to be expected from different kinds of irregularity in surfaces; but these effects need some mathematical examination before anything can be said of them sufficiently definite to be useful.

XIV.

MEAN RIGHT ASCENSIONS OF 133 STARS NEAR THE NORTH POLE, OBSERVED IN 1882 AND 1883, AT THE FIELD MEMORIAL OBSERVATORY OF WILLIAMS COLLEGE.

BY TRUMAN HENRY SAFFORD.

Presented April 9, 1884.

THE Observatory of Williams College is at present composed of two buildings at some distance apart. The old, or Hopkins Observatory, contains a Clark equatorial of 7½ inches aperture, whose mounting by another maker is old and unsatisfactory, and a Simms transit of 3¾ inches aperture, of ancient date, and in need of repairs. These instruments are employed for practice by the students, to whom the situation in the College grounds is convenient; but their horizon is much encroached upon by trees and buildings. This is the oldest observatory now in use in this country.

The newer, or Field Memorial Observatory, now consists of an iron house, containing the Repsold meridian circle, with which the following observations were made. The situation of this house is better adapted to observation; it is upon a slight elevation about a quarter of a mile from the College buildings, with a horizon bounded only by the neighboring mountains, Greylock in the southeast, the Taconics of New York in the west, and the hills of Vermont in the north. The instrument, of 4½ inches (French) in aperture, was completed in 1881; but the building was delayed quite needlessly by the contractors, so that the mounting did not take place until June, 1882, and the observations here given were begun a few weeks later. The intervening time was spent in getting the instrument into proper adjustment, and in the business of the annual Commencement. A few observations were made before the focal adjustment; these have not been reduced, except to rate the clock, which is an old one, removed from the Hopkins Observatory.

The new building, the instrument, and the fund which renders it possible to carry on astronomical observations, are the gifts of the same gentleman, the Hon. David Dudley Field, of New York City, well known in all civilized countries for his services to international jurisprudence.

The series of observations here presented is, it is hoped, the beginning of a large catalogue of stars. It is published in this form in order to set forth some principles, which, as I believe, represent the present state of practical astronomy with regard to the construction of a secondary catalogue; and to interest other observers in the application of these principles.

These observations are also intended, in connection with earlier ones upon the same stars, to meet a definite practical necessity for an extensive catalogue of polar right ascensions for various purposes of practical astronomy and geodesy. There are many observations whose final discussion, especially with respect to systematic corrections, will need to be based upon a combination of such catalogues as the one here presented; and the need of more such, especially for the latest epochs, is sensibly felt by all who have been obliged to make time-observations in the field for telegraphic longitudes. This is especially true in our Western Territories; the telegraphic communications are often precarious, and an accurate catalogue which enables the astronomer to determine his time, by portable instruments, in half an hour, with the precision of a fixed observatory, would often be of great assistance towards economy of labor.

I have already published such a catalogue of polar right ascensions for 1865, and its repetition on a more extensive scale is now, I think, timely. Certain unsolved questions relating to personal equation will also be advanced towards a solution by the speedy publication of the materials here collected.

The method of observation is the following.

At the beginning of an evening's work the time is determined, as well as the deviation of the instrument from the pole, Bessel's n, by stars from the Berlin Jahrbuch. These observations are followed by a set of observations of stars to be determined, and the evening's work concluded by other stars from the Berlin Jahrbuch. From the beginning I have taken pains that every determined star should be preceded and followed by enough standard stars to make the interpolation of the n perfectly certain, and to give the n a weight of at least two observations of the star to be determined. Latterly, as the precision of the observations has become greater, I have taken similar

pains with the clock corrections; so that now the framework of a good evening's observation is the following: —

$\begin{cases} \text{2–3 standard polars.} \\ \text{2 \quad " \quad time stars.} \end{cases}$

Stars to be determined.

$\begin{cases} \text{2–3 standard polars.} \\ \text{2 time stars.} \end{cases}$

It sometimes happens, however, that a star to be determined is preceded by an observation upon five wires and followed by another upon five wires of a close standard polar, like Polaris or λ Ursæ Minoris.

In case the weather changes during the evening, I have considered it safe to employ a one-sided determination of *n* and of the clock correction whenever the mean of the transits of the two or three standard polars is within an hour of that of the star to be determined.

The standard polars used by preference are those of the Jahrbuch within 10° of the pole; those between 5° and 10° receive three-fourths weight. When it is necessary to go beyond 10°, stars between 10° and 20° receive one-half weight. Such stars of the Jahrbuch as are given in the following catalogue are beyond 10°, and the observations here given have in no case been employed to determine the polar deviation.

The collimation has been determined by combination of level and nadir, or, latterly, by two collimators; one of these has an aperture of 2½ inches, and is an ordinary telescope with tube, pivots, level, and micrometer; the other is composed of a long-focus object-glass of five inches aperture and a temporary meridian mark, to be later replaced by a permanent apparatus, provided by the makers, but not yet mounted.

In the use of the catalogue of the Jahrbuch the only point to be especially noted is, that polar stars whose places are relatively uncertain have been, so far as possible, avoided. Their uncertainty has been pointed out by Professor Auwers, the author of the catalogue; and is mainly owing to proper motion. The best stars are those which were observed by Bradley twice or more. One pair of stars (76 Draconis above pole, and Draconis 1 H. below, or *vice versa*) gave values of *n* differing systematically from each other by over $0^s.1$; but it so happened that the mean correction, derived from later observations of both, combined with a new investigation of their proper motions, was almost exactly zero; so that I made it a rule to observe the pair

together, leaving the more refined investigation of the necessary corrections to a later date. At first I employed the standard polars between 10° and 20° polar distance more freely than later.

Whenever stars beyond 10° of the pole were employed to determine n they received a weight of one half, and those between 5° and 10° a weight of three fourths; those within 5° (of which the Jahrbuch gives daily ephemerides) represented the unit of weight; the probable error of an n corresponding to this unit has been, in the mean, not far from $\pm 0^s.020$. This probable error, however, does not include the whole of the errors in the Jahrbuch places, but is somewhat greater than would be given by perfect standard right ascensions reduced to my method of observing. Omitting those stars beyond 10° of polar distance, for which I have no great number of observations, and eliminating errors of star places and personal equation, but making no distinction between observations in different positions of the instrument, I obtain $\pm 0^s.018$ for the probable error of a transit, weight $= 1$. This includes a fair average of the earlier, less precise observations.

In the tables which follow are given the separate results for each night, as they were derived from the immediate reduction. The calculations were not, strictly speaking, duplicated; but a course was pursued which left very little chance of error. The first thing to be noted is, that only those stars were reduced which have been four or more times observed between July, 1882, and December, 1883. It is intended to observe each star's right ascension eight times, in two different positions; and to double or quadruple this number for the more important polars.

All stars within 10° of the pole brighter than the magnitude 7.5 (Durchmusterung), all in the same region which are fainter but important from proper motion, and all others, wherever situated, which I can find to have been anywhere used as standard northern polars, are included in the working list. Each such star might be observed in eight positions, as the instrument is reversible, and its object-glass and eyepiece interchangeable, if we included observations below the pole. Two of these positions, four observations in each, will suffice for the majority of stars; four positions, for the stars of Professor Albrecht's catalogue, prepared for the European geodetic association; while the eight positions, or 32 observations, will be adopted for stars within 10° of polar distance whose places are given in the ephemerides. The more important standard polars of the Jahrbuch will not be definitively determined until the mark is permanently set up: at present

their observations furnish only values of n and equations of condition (not here given) among the various stars.

The instrument was not reversed during the present series, but the eye-piece and object-glass were interchanged, September 4, 1883. Before that date the observations were not so accurate as afterwards, owing to various small causes of error. The instrument was liable to slight strains, until the counterpoises were properly regulated; this affects the observations up to April 17, 1883. There was a month's interruption after this date, due to illness. The collimation was a little uncertain during the winter; the assistant who determined it by level and nadir met with some difficulty in levelling, and his results were not very accordant. The clock was frequently inaudible; much of the time an assistant gave me the ticks during transits, and relief was finally obtained by a galvanic connection with a telegraphic sounder. This took place in or about July, 1883. The exchange of object-glass and eyepiece put an end to a trouble with the field illumination, which was due seemingly to a displacement of the prisms in transportation.

Very few observations are made upon less than five wires; half-weight* is given to one or two wires; and in the case of the stars nearest the pole the movable vertical wire is freely used. As its coincidence with the fixed wire varies a little with the temperature, it is necessary to determine its coincidence with the central fixed wire very carefully. The reductions to mean place have been effected with the data of the American Ephemeris, — which agree closely with those of the Jahrbuch, — and have been duplicated in many cases, employing Bessel's two sets of formulæ. As declinations have not been observed, they have been pretty carefully computed from modern catalogues, so that their values as employed are usually correct to 1″.

* More frequently the half-weight is due to a combination of unfavorable circumstances noted at the time of observation, or in one case to large and irregular changes in the instrumental correction, so that its true value was uncertain. One observation has been rejected for this reason; but may perhaps prove reducible later.

MEAN RIGHT ASCENSIONS FOR 1883.0.

Results of Separate Observations.

Bradley 48.

	h. m.	s.
1883, Nov. 7	0 30	59.33
16		58.90
27		59.14
Dec. 6		59.12
Mean A. R. 1883.0	0 30	59.122

Bradley 74.

	h. m.	s.
1883, May 17 s. p.	0 44	0.46
June 1 s. p.		0.21
Nov. 16		0.54
27		0.63
Dec. 6		0.49
15		0.64
Mean A. R. 1883.0	0 44	0.495

Bradley 65.

	h. m.	s.
1883, May 29 s. p.	0 51	29.87
June 1 s. p.		29.42
Nov. 7		28.08
27		27.34
Dec. 6		27.74
15		27.49
Mean A. R. 1883.0	0 51	28.328

Bradley 95.

	h. m.	s.
1883, May 25 s. p.	0 56	37.95
29 s. p.		39.00
June 1 s. p.		38.49
8 s. p.		38.12
Mean A. R. 1883.0	0 56	38.390

38 Cassiopeiæ A. E.

	h. m.	s.
1882, Dec. 8		+0.33
12 [wt. = ½]		+0.69
15		+0.14
1883, Jan. 15		0.00
		+0.233
A. E.		32.314
Mean A. R. 1883.0	1 22	32.547

Groombridge 389.

	h. m.	s.
1883, June 5 s. p.	1 36	55.32
8 s. p.		54.63
12 s. p.		55.57
14 s. p.		54.19
Mean A. R. 1883.0	1 36	54.928

Schwerd 75.

	h. m.	s.
1883, June 5 s. p.	1 44	1.42
8 s. p.		1.79
12 s. p.		2.57
14 s. p.		2.46
Mean A. R. 1883.0	1 44	2.060

Groombridge 424.

	h. m.	s.
1882, Dec. 8	1 55	5.12
15		4.61
1883, June 9 s. p.		4.93
14 s. p.		5.02
15 s. p.		4.88
Mean A. R. 1883.0	1 55	4.912

Bradley 344.

	h. m.	s.
1882, Dec. 12 [wt. = ½]	2 31	1.25
15	30	59.98
1883, Feb. 7	31	0.75
8		0.64
June 14 s. p.		0.44
22 s. p.		0.04
23 s. p.		0.20
25 s. p.		0.07
Mean A. R. 1883.0	2 31	0.366

Groombridge 642.*

	h. m.	s.
1882, July 20 s. p	3 28	20.25
1883, Jan. 18		20.45
Feb. 5		19.57
7		20.26
8		19.86
June 22 s. p.		20.18
25 s. p.		19.69
July 10 s. p.		19.37
Mean A. R. 1883.0	3 28	19.954

* In reducing these observations to 1883.0, a yearly proper motion of $+0^s.164$ was employed.

MEAN RIGHT ASCENSIONS FOR 1883.0. — *Continued.*

Groombridge 766.

	h.	m.	s.
1883, July 18 s. p.	4	1	12.03
19 s. p.			12.00
20 s. p.			12.19
23 s. p.			11.97
Mean A. R. 1883.0	4	1	12.048

Groombridge 774.

	h.	m.	s.
1883, July 20 s. p.	4	4	22.50
23 s. p.			22.75
24 s. p.			22.93
25 s. p.			23.03
Mean A. R. 1883.0	4	4	22.802

Groombridge 779.

	h.	m.	s.
1882, July 22 s. p.	4	6	45.04
24 s. p.			44.90
25 s. p.			44.59
1883, Jan. 18			44.59
23			44.75
July 10 s. p.			44.34
14 s. p.			44.28
Mean A. R. 1883.0	4	6	44.641

Groombridge 785.

	h.	m.	s.
1883, Jan. 23	4	9	4.65
31			4.61
July 11 s. p.			4.78
14 s. p.			4.21
16 s. p.			4.65
18 s. p.			5.09
Mean A. R. 1883.0	4	9	4.665

Schwerd 242.

	h.	m.	s.
1883, Jan. 18	4	16	12.91
23			12.85
31			12.85
July 11 s. p.			12.55
14 s. p.			12.62
16 s. p.			12.54
18 s. p.			12.71
Mean A. R. 1883.0	4	16	12.719

Schwerd 241.

	h.	m.	s.
1883, July 10 s. p.	4	17	30.10
11 s. p.			29.54
14 s. p.			29.55
16 s. p.			29.67
Mean A. R. 1883.0	4	17	29.715

Piazzi IV. 59.

	h.	m.	s.
1883, Jan. 18	4	25	36.13
23			36.19
31			36.52
Feb. 23			36.27
July 11 s. p.			35.86
14 s. p.			36.05
16 s. p.			35.89
18 s. p.			36.20
Mean A. R. 1883.0	4	25	36.139

Piazzi IV. 77.

	h.	m.	s.
1883, Jan. 18	4	28	36.83
23			37.01
31			37.17
Feb. 23			37.07
July 11 s. p.			37.17
14 s. p.			37.12
16 s. p.			36.76
18 s. p.			37.04
Mean A. R. 1883.0	4	28	37.021

Groombridge 848.

		h.	m.	s.
1883, July 18 s. p.	B. J.			+0.15
20 s. p.				+0.11
23 s. p.				−0.21
26 s. p.				−0.38
30 s. p.				−0.17
	Mean			−0.100
	B. J.			6.616
Mean A. R. 1883.0		4	33	6.516

Cephei 50 H.

	h.	m.	s.
1882, July 24 s. p.	4	38	30.07
25 s. p.			30.40
1883, Jan. 18			30.16
23			30.12
31			30.26
Feb. 23			30.06
July 11 s. p.			30.07
14 s. p.			30.65
Mean A. R. 1883.0	4	38	30.224

MEAN RIGHT ASCENSIONS FOR 1883.0. — *Continued.*

Radcliffe 1311.

	h. m. s.
1882, July 24 s. p.	4 50 27.70
25 s. p.	28.23
1883, Jan. 31	27.27
Feb. 23	27.84
July 20 s. p.	26.91
23 s. p.	27.65
Mean A. R. 1883.0	4 50 27.600

Camelopardali 19 H.

		s.
1882, July 30 s. p.	B. J.	+0.28
Aug. 3 s. p.		+0.23
4 s. p.		+0.21
6 s. p.		+0.25
8 s. p.		+0.17
9 s. p.		+0.23
11 s. p.		+0.38
21 s. p.		+0.08
22 s. p.		+0.10
	Mean	+0.209
	B. J.	17.735
		h. m. s.
Mean A. R. 1883.0		5 3 17.944

Radcliffe 1377.

	h. m. s.
1882, July 21 s. p.	5 4 14.35
24 s. p.	14.11
1883, Jan. 31	13.85
July 20 s. p.	13.65
23 s. p.	13.71
Mean A. R. 1883.0	5 4 13.934

Schwerd 306.

	h. m. s.
1883, July 20 s. p.	5 7 32.77
24 s. p.	32.71
30 s. p.	32.99
31 s. p.	32.70
Mean A. R. 1883.0	5 7 32.792

Groombridge 966.

		s.
1883, July 23 s. p.	B. J.	—0.04
24 s. p.		—0.25
Aug. 6 s. p.		—0.11
9 s. p.		—0.34
11 s. p.		—0.06
14 s. p.		—0.31
	Mean	—0.185
	B. J.	5.196
		h. m. s.
Mean A. R. 1883.0		5 24 5.011

Groombridge 944.

		s.
1882, July 20 s.p.	A.E.(Suppl.)	+0.37
21 s.p.		+0.21
1883, Feb. 13		—0.72
Mar. 5		+0.08
July 20 s. p.		—0.44
23 s. p.		—0.22
	Mean	—0.120
	A.E.(Suppl.)	37 900
		h. m. s.
Mean A. R. 1883.0		5 24 37.780

Groombridge 1004.

	h. m. s.
1882, July 20 s. p.	6 0 29.58
21 s. p.	30.17
1883, Feb. 8	28.85
13	28.12
Mar. 1	29.33
5	29.88
July 30 s. p.	28.81
Aug. 3 s. p.	28.50
Mean A. R. 1883.0	6 0 29.092

Schwerd 362.

	h. m. s.
1883, Mar. 8	6 13 48.09
22	47.87
Aug. 3 s. p.	47.61
4 s. p.	47.69
8 s. p.	47.22
9 s. p.	47.71
Mean A. R. 1883.0	6 13 47.698

Schwerd 369.

	h. m. s.
1883, Feb. 13	6 19 44.84
Mar. 1	45.51
8	45.78
22	45.45
July 30 s. p.	45.53
Aug. 3 s. p.	45.30
4 s. p.	45.35
6 s. p.	45.55
Mean A. R. 1883.0	6 19 45.414

Schwerd 377.

	h. m. s.
1883, July 30 s. p.	6 25 58.20
Aug. 3 s. p.	57.82
4 s. p.	58.10
6 s. p.	57.94
Mean A. R. 1883.0	6 25 58.015

MEAN RIGHT ASCENSIONS FOR 1883.0. — *Continued.*

Camelopardali 23 H.

		s.
1883, Sept. 6	B. J.	+0.22
15		—0.20
17		+0.12
18		—0.24
19		+0.02
Oct. 3		+0.42
	Mean	+0.057
	B. J.	14.649
	h. m.	s.
Mean A. R. 1883.0	6 26	14.706

Camelopardali 24 H.

		s.
1883, Sept. 15	B. J.	—0.01
17 [wt. = ½]		+0.50
18		—0.24
Oct. 1		+0.45
3		+0.16
5		—0.01
	Mean	+0 109
	B. J.	59.109
	h. m.	s.
Mean A. R. 1883.0	6 42	59.218

Groombridge 1255.

	h. m.	s.
1883, Feb. 23	7 3	7.02
Mar. 1		7.00
8		6.82
13		7.12
Sept. 18 s. p.		6.79
19 s. p.		6.80
Oct. 1 s. p.		6.85
3 s. p.		6.82
Mean A. R. 1883.0	7 3	6.902

Camelopardali 25 H.

		s.
1882, Sept. 9 s. p.	A. E. Suppl.	—0.34
12 s. p.		—0.88
15 s. p. [wt. = ½]		—0.03
16 s. p.		—0.64
Oct. 10 s. p.		—0.60
1883, Feb. 7		—0.46
23		—0.26
Mar. 1		—0.34
8		+0.10
Sept. 5 s. p.		—0.60
6 s. p.		—0.41
17 s. p.		—0.18
18 s. p.		—0.52
19 s. p.		—0 82
	Mean	—0.442
	A. E.	23.837
	h. m.	s.
Mean A. R. 1883.0	7 6	23.395

Schwerd 406.

	h. m.	s.
1883, Mar. 1	7 9	11.25
8		10.37
13		10.79
16		10.12
21		10.20
Mean A. R. 1883.0	7 9	10.546

Schwerd 415.

	h. m.	s.
1883, Feb. 23	7 11	25 69
Mar. 1		26.15
13		25.71
16		25.64
21		25.34
Mean A. R. 1883.0	7 11	25.706

Groombridge 1278.

	h. m.	s.
1883, Aug. 8 s. p.	7 18	17.85
Sept. 5 s. p.		17.33
6 s. p.		17.50
17 s. p.		17.64
19 s. p.		17.70
Mean A. R. 1883.0	7 18	17.604

Schwerd 424.

	h. m.	s.
1883, Mar. 1	7 22	2.61
8		2.50
13		2.60
16		2.32
21		2.24
Sept. 19 s. p.		2.44
26 s. p.		2.52
Oct. 1 s. p.		2.32
3 s. p.		2.41
Mean A. R. 1883.0	7 22	2.440

Camelopardali 28 H.

	h. m.	s.
1882, Oct. 21	7 36	52.84
26 s. p.		53.76
30 s. p.		53.10
1883, Mar. 13		53.06
16		52.83
29		52.86
April 6		53.22
Sept. 19 s. p.		52.76
22 s. p.		52.50
26 s. p.		53.15
Oct. 1 s. p.		52.72
3 s. p.		52.81
Mean A. R. 1883.0	7 36	52.968

MEAN RIGHT ASCENSIONS FOR 1883.0. — *Continued.*

Groombridge 1119.

Date		s.
1882, Sept. 9 s. p.	C. des T.	+5.43
12 s. p.		8.00
15 s. p.		7.82
16 s. p.		6.48
1883, Feb. 7		4.91
19		8.62
23		9.08
Mar. 1		5.69
Sept. 5 s. p.		5.10
6 s. p.		6.98
15 s. p.		2.71
18 s. p.		3.09
	Mean	+6.155
	C. des T.	37.86
		h. m. s.
Mean A. R. 1883.0		7 38 44.015

Groombridge 1355.

Date	h. m.	s.
1883, Sept. 21 s. p.	7 40	30.27
22 s. p.		30.14
26 s. p.		30.34
Oct. 1 s. p.		30.25
Mean A. R. 1883.0	7 40	30.250

Groombridge 1368.

Date	h. m.	s.
1883, Feb. 23	7 46	20.13
Mar. 13		20.55
16		20.23
23		19.69
24		20.22
Sept. 22 s. p.		20.10
Oct. 1 s. p.		20.10
5 s. p.		20.12
9 s. p.		20.00
Mean A. R. 1883.0	7 46	20.127

Radcliffe 2020.

Date	h. m.	s.
1883, Mar. 13	7 46	45.88
24		45.24
29		45.27
April 6		46.46
Oct. 15 s. p.		45.44
22 s. p.		45.29
Mean A. R. 1883.0	7 46	45.597

Groombridge 1359.

Date	h. m.	s.
1882, Sept. 16 s. p.	7 48	46.02
Oct. 28 s. p.		45.96
30 s. p.		45.88
31 s. p. [wt. = ½]		45.32
1883, Mar. 16		45.84
21 [wt. = ½]		45.02
23		45.30
24		45.69
28		46.02
Sept. 22 s. p.		46.56
Oct. 5 s. p.		45.97
9 s. p.		45.53
11 s. p.		46.00
Mean A. R. 1883.0	7 48	45.828

Groombridge 1391.

Date	h. m.	s.
1882, Oct. 28 s. p.	8 1	46.91
30 s. p.		46.75
Nov. 10 s. p.		46.79
1883, Mar. 13		47.22
16		46.54
23		46.50
24		46.64
28		47.23
Oct. 1 s. p.		46.84
5 s. p.		47.25
22 s. p.		46.82
Mean A. R. 1883.0	8 1	46.863

Groombridge 1418.

Date	h. m.	s.
1882, Sept. 16 s. p.	8 20	38.68
Oct. 7 s. p.		38.87
26 s. p.		39.36
28 s. p.		38.83
1883, Mar. 13		39.79
21		38.20
23		38.73
28		39.62
Mean A. R. 1883.0	8 20	39.010

Groombridge 1431.

Date	h. m.	s.
1883, Mar. 21	8 25	6.61
23		6.48
29		6.90
April 2		6.95
Sept. 15 s. p.		6.60
Oct. 3 s. p.		6.74
5 s. p.		7.01
22 s. p.		6.96
Mean A. R. 1883.0	8 25	6.781

MEAN RIGHT ASCENSIONS FOR 1883.0. — *Continued.*

Schwerd 529.

	h.	m.	s.
1882, Nov. 10 s. p.	8	38	31.88
15 s. p.			31.42
16 s. p.			31.78
18 s. p.			31.64
1883, April 2			31.44
6			31.81
9			32.12
10			31.92
Mean A. R. 1883.0	8	38	31.751

Schwerd 533.

	h.	m.	s.
1882, Oct. 30 s. p.	8	41	15.51
Nov. 4 s. p.			15.31
6 s. p.			15.99
8 s. p.			16.05
1883, Mar. 23			15.83
24			15.80
29			16.18
April 2			15.89
Mean A. R. 1883.0	8	41	15.820

Radcliffe 2218.

	h.	m.	s.
1882, Oct. 7 s. p.	8	50	43.89
13 s. p.			44.22
14 s. p.			43.48
Nov. 6 s. p.			43.90
8 s. p.			44.00
1883, Mar. 29			44.10
April 2			44.24
6			44.77
9			44.21
Mean A. R. 1883.0	8	50	44.090

Groombridge 1480.

	h.	m.	s.
1883, April 10	8	53	38.52
13			38.57
14			39.25
17			38.72
Mean A. R. 1883.0	8	53	38.765

Schwerd 587.

	h.	m.	s.
1883, April 2	9	44	41.06
14			41.77
17			40.80
Oct. 17 s. p.			41.12
Nov. 27 s. p.			41.40
29 s. p.			41.52
Mean A. R. 1883.0	9	44	41.278

Radcliffe 2404.

	h.	m.	s.
1883, Mar. 20	9	49	40.82
22			39.82
April 2			40.19
10			40.32
Oct. 17 s. p.			40.64
Nov. 27 s. p.			39.76
28 s. p.			40.86
29 s. p.			40.47
Mean A. R. 1883.0	9	49	40.360

Radcliffe 2407.

	h.	m	s.
1883, Mar. 20	9	58	13.82 *
April 2			11.63
17			11.83
Oct. 17 s. p.			13.55
Mean A. R. 1883.0	9	58	12.708

Camelopardali 29 H.

	h.	m.	s.
1882, Oct. 13 s. p.	10	12	28.12 †
Dec. 9 s. p.			26.46
12 s. p.			26.76
1883, Mar. 20			27.34
22			26.47
April 14			26.99
17			27.07
Oct. 17 s. p.			27.08
Nov. 27 s. p.			26.29
28 s. p.			27.01
Dec. 3 s. p.			26.86
6 s. p.			26.26
Mean A. R. 1883.0	10	12	26.892

* This star, a close polar, was observed with the micrometer: and for this date the micrometrical zero-point is apparently ill-determined

† This observation is discrepant, probably owing to a change in the position of the instrument, but the seeing was also very bad, and I have retained it unchanged for uniformity's sake, leaving any correction to a final discussion of a few suspected evenings. As soon as nearly final right-ascensions of all the stars observed on this date shall be ready, it will be possible to follow the changes in the value of n from $18^h.8$ to $22^h.3$ sidereal time, and decide whether the discrepancies in this quantity are accidental or progressive; at present Cephei 51 H. s p gives $n+c = +1^s.949$; Camelopardali 30 H. s. p. $+2^s.113$. I had attributed the difference to the wretched seeing in assigning the mean, and so reduced all the observations.

MEAN RIGHT ASCENSIONS FOR 1883.0. — *Continued.*

Radcliffe 2594.

	h.	m.	s.
1882, Oct. 28 s. p.	11	0	19.59
Nov. 4 s. p.			18.31
10 s. p.			16.08
16 s. p.			19.83
1883, Oct. 17 s. p.			18.00
Nov. 16 s. p.			17.23
Mean A. R. 1883.0	11	0	18.178

Groombridge 1782.

	h.	m.	s.
1882, Oct. 20 s. p.	11	23	32.60
28 s. p.			32.89
Nov. 4 s. p.			32.17
10 s. p.			32.00
Mean A. R. 1883.0	11	23	32.415

Groombridge 1850.

	h.	m.	s.
1882, Nov. 4 s. p.	11	58	51.34
10 s. p.			50.66
1883, Dec. 26 s. p.			50.61
29 s. p.			49.96
Mean A. R. 1883.0	11	58	50.642

Bradley 1656.

	h.	m.	s.
1883, May 29	12	13	25.50
Oct. 15 s. p.			25.27
Nov. 7 s. p.			24.93
16 s. p.			25.05
Dec. 26 s. p.			25.53
Mean A. R. 1883.0	12	13	25.256

Bradley 1672.

		h.	m.	s.
1882, Nov. 10 s. p.	C. des T.			+0.77
18 s. p.				+2.41
21 s. p.				+2.17
1883, May 17				+2.68
18				+2.62
25				+2.98
28				+4.22
Oct. 15 s. p.				+2.06
Nov. 7 s. p.				+1.42
16 s. p.				+2.59
Dec. 26 s. p.				+2.02
	Mean			+2.358
	C. des T.			18.30
Mean A. R. 1883.0		12	14	20.658

Groombridge 1923.

	h.	m.	s.
1882, Nov. 21 s. p.	12	37	32.54
1883, May 17			32.92
25			33.08
29			33.21
June 1			33.66
Nov. 27 s. p.			32.42
Mean A. R. 1883.0	12	37	32.972

Groombridge 1927.

	h.	m.	s.
1883, May 17	12	41	27.79
25			27.67
29			27.60
June 1			28.50
Nov. 7 s. p.			27.70
Dec. 6 s. p.			27.61
29 s. p.			27.59
Mean A. R. 1883.0	12	41	27.780

Camelopardali 32 H. foll.

		h.	m.	s.
1882, Oct. 20 s. p.	A. E.			—0.20
Nov. 21 s. p.				—0.62
Dec. 9 s. p.				—0.02
1883, Jan. 11 s. p.	[wt. = ½]			—0.95
12 s. p.				—0.79
15 s. p.				—0.43
May 17				—0.10
18				—0.12
25				—0.65
28				—0.20
Oct. 15 s. p.				—0.50
Nov. 16 s. p.				—0.38
27 s. p.				—0.51
Dec. 6 s. p.				—0.64
	Mean			—0.417
	A. E.			16.753
Mean A. R. 1883.0		12	48	16.336

Groombridge 2006.

	h.	m.	s.
1883, June 1	13	7	7.17
8			6.42
Nov. 16 s. p.			6.79
27 s. p.			6.70
28 s. p.			6.85
Dec. 6 s. p.			6.82
Mean A. R. 1883.0	13	7	6.792

MEAN RIGHT ASCENSIONS FOR 1883.0.— *Continued.*

Groombridge 2007.

	h.	m.	s.
1883, May 25	13	19	22.64
June 1			22.16
5			21.94
8			22.75
Nov. 27 s. p.			22.16
28 s. p.			22.41
Dec. 6 s. p.			21.75
15 s. p.			21.88
Mean A. R. 1883.0	13	19	22.211

Groombridge 2068.

	h.	m.	s.
1883, June 8	13	45	43.54
9			43.59
12			43.37
14			43.86
15			43.81
Mean A. R. 1883.0	13	45	43.634

Groombridge 2071.

	h.	m.	s.
1883, June 8	13	52	44.68
9			44.53
14			44.71
15			44.78
Mean A. R. 1883.0	13	52	44.675

Groombridge 2099.

	h.	m.	s.
1882, Dec. 8 s. p.	14	1	29.10
12 s. p. [wt. = ½]			27.43
15 s. p.			30.08
1883, Jan. 22 s. p.			29.19
23 s. p.			28.40
June 5			28.36
12			28.26
14			27.78
15			28.53
Mean A. R. 1883.0	14	1	28.637

5 Ursæ Minoris.

		s.
1883, June 14	A. E.	+0.11
22		—0.07
23		+0.08
25		+0.14
	Mean	+0.065
	A. E.	47.155

	h.	m.	s.
Mean A. R. 1883.0	14	27	47.220

Groombridge 2196.

	h	m.	s.
1883, Feb. 7 s. p.	14	58	18.17
8 s. p.			18.21
12 s. p.			17.91
June 22			18.02
23			18.33
25			18.28
July 10			18.29
Mean A. R. 1883.0	14	58	18.173

Groombridge 2218.

	h.	m.	s.
1883, Feb. 7 s. p.	15	3	33.89
8 s. p.			33.97
June 28			34.08
July 11			33.46
Mean A. R. 1883.0	15	3	33.850

Groombridge 2233.

		s.
1883, Jan. 18 s. p.	C. des T.	—2.75
Feb. 5 s. p.		—1.37
7 s. p.		—2.16
8 s. p.		—1.88
June 14		—2.63
15		—1.55
22		—2.70
July 10		—2.68
	Mean	—2.215
	C. des T.	22.18

	h.	m.	s.
Mean A. R. 1883.0	15	15	19.965

11 Ursæ Minoris.

	h.	m.	s.
1883, June 14	15	17	11.67
22			11.90
July 11			11.66
14			12.04
Mean A. R. 1883.0	15	17	11.818

Groombridge 2275.

	h.	m.	s.
1883, Jan. 18 s. p.	15	36	1.22
Feb. 12 s. p.			1.08
June 25			1.59
July 11			1.45
14			1.74
16			1.92
Mean A. R. 1883.0	15	36	1.500

MEAN RIGHT ASCENSIONS FOR 1883.0. — *Continued.*

Groombridge 2276.

	h.	m.	s.
1883, Jan. 18 s. p.	15	36	13.92
Feb. 12 s. p.			13.64
June 25			14.18
July 11			14.28
14			14.44
16			14.49
Mean A. R. 1883.0	15	36	14.158

Radcliffe 3445.

	h.	m.	s.
1883, June 22	15	37	3.09
July 10			2.94
11			2.77
14			2.93
Mean A. R. 1883.0	15	37	2.932

Schwerd 932.

	h.	m.	s.
1883, July 10	15	44	2.42
11			2.50
14			3.00
16			2.79
Mean A. R. 1883.0	15	44	2.678

Radcliffe 3475.

	h.	m.	s.
1883, July 10	15	45	22.48
14			23.12
16			22.40
18			23.21
Mean A. R. 1883.0	15	45	22.802

18 Ursæ Minoris.

	h.	m.	s.
1883, Feb. 19 s. p.	15	46	6.29
July 11			5.82
14			6.12
16			6.13
18			6.01
Mean A. R. 1883.0	15	46	6.074

Schwerd 945.

	h.	m.	s.
1883, July 14	15	52	36.38
16			36.07
18			36.65
20			37.08
Mean A. R. 1883.0	15	52	36.545

Groombridge 2315.

	h.	m.	s.
1883, Jan. 18 s. p.	15	55	38.98
23 s. p.			38.56
Feb. 12 s. p.			39.25
19 s. p.			39.25
June 22			38.76
July 11			39.17
14			39.56
16			38.43
Mean A. R. 1883.0	15	55	38.995

A Draconis.

			s.
1883, July 19	B. J.		+0.28
20			+0.26
23			+0.17
24			+0.20
30			+0.26
	Mean		+0.230
	B. J.		12.884
	h.	m.	s.
Mean A. R. 1883.0	16	28	13.114

Schwerd 988.

	h.	m.	s.
1883, July 10	16	36	4.19
11			3.96
14			4.30
16			3.86
Mean A. R. 1883.0	16	36	4.078

Schwerd 986.

	h.	m.	s.
1883, July 16	16	38	52.97
18			52.95
19			53.34
20			53.27
Mean A. R. 1883.0	16	38	53.132

Schwerd 1016.

	h.	m.	s.
1883, July 24	17	6	13.47
30			13.59
31			13.37
Aug. 3			13.72
Mean A. R. 1883.0	17	6	13.538

Groombridge 2456.

	h.	m.	s.
1883, Feb. 18 s. p.	17	28	29.48
Mar. 5 s. p.			30.15
July 20			30.06
24			29.90
26			30.06
30			29.77
Mean A. R. 1883.0	17	28	29.895

MEAN RIGHT ASCENSIONS FOR 1883.0. — *Continued.*

Groombridge 2476.

		h. m. s.
1883, Feb. 18	s. p.	17 35 2.57
Mar. 1	s. p.	2.50
5	s. p.	2.34
Aug. 14		2.63
21		2.51
22		2.50
Mean A. R. 1883.0		17 35 2.508

ψ Draconis (Southern Star).

		s.
1883, July 23	B. J.	+0.24
24		+0.11
Aug. 3		+0 20
4		+0.31
6		+0.21
8		+0.30
11		+0.30
	Mean	+0.239
	B. J.	1.223
		h. m. s.
Mean A. R. 1883.0		17 44 1.462

Schwerd 1059.

	h. m. s
1883, July 30	17 51 26.31
Aug. 3	26 23
4	26.34
6	26.25
Mean A. R. 1883.0	17 51 26.282

35 Draconis.

		s.
1883, Aug. 4	B. J.	+0.02
6		+0.11
9		+0.04
11		+0.14
14		+0.01
21		+0.12
22		+0.05
	Mean	+0.070
	B. J.	41.285
		h. m. s.
Mean A. R. 1883.0		17 54 41.355

40 Draconis.

	h. m. s.
1883, Aug. 6	18 8 47.60
8	47.81
9	47.67
11	47.66
Mean A. R. 1883.0	18 8 47.685

41 Draconis.

	h m. s.
1883, Aug. 6	18 8 53.78
8	54.04
9	53.98
11	54.06
Sept. 6	53.79
19	53.70
Mean A. R. 1883.0	18 8 53.892

24 Ursæ Minoris.

		h. m. s.
1883, Feb. 8	s. p.	18 14 6.93
13	s. p.	5.94
27	s. p.	6.62
Mar. 1	s. p.	5.80
July 30		5.98
Aug. 3		6.11
4		6.07
6		5.47
Sept. 6		6.55
15		6.62
18		6.58
19		5 23
Mean A. R. 1883.0		18 14 6.154

χ Draconis.

		s.
1883, Aug. 14	B. J.	+0.19
Sept. 6		+0.07
15		+0.14
17	[wt. = ½]	+0.33
18		—0.28
19		—0.10
Oct. 3		+0.02
5		—0.21
9		—0.19
10		—0.09
13		—0.02
15		+0.03
17		—0.15
	Mean	—0.034
	B. J.	9.902
		h. m. s.
Mean A. R. 1883.0		18 23 9.868

Radcliffe 3961.

		h. m. s.
1883, Feb. 13	s. p.	18 24 3.72
Mar. 1	s. p.	3.70
8	s. p.	3.95
22	s. p.	3.72
July 30		4.03
Aug. 3		3.83
4		4.18
6		4.06
Mean A. R. 1883.0		18 24 3.901

MEAN RIGHT ASCENSIONS FOR 1883.0. — *Continued.*

Bradley 2412.

Date		h. m. s.
1882, July 20		18 39 34.30
Sept. 9		34.78
12		34.81
1883, Mar. 1 s. p.		34.86
8 s. p.		34.52
13 s. p.		34.70
22 s. p.		34.21
Sept. 6		34.59
15		34.56
17		34.59
18		34.69
19		34.59
Mean A. R. 1883.0		18 39 34.600

50 Draconis.

Date		s.
1883, Sept. 15	A. E.	+0.07
18		+0.01
19		+0.14
Oct. 3		+0.28
	Mean	+0.125
	A. E.	8.402
		h. m. s.
Mean A. R. 1883.0		18 50 8.527

Radcliffe 4208.

Date		h. m. s.
1882, Sept. 9		18 53 1.97
12		1.98
16		2.42
1883, Mar. 16 s. p.		2.53
Aug. 8		1.47
Mean A. R. 1883.0		18 53 2.074

υ Draconis.

Date		s.
1883, Oct. 9	B. J.*	—0.16
11		—0.10
15		—0.07
16		+0.11
17		+0.12
18		—0.10
	Mean	—0.033
	B. J.	49.662
		h. m. s.
Mean A. R. 1883.0		18 55 49.629

Radcliffe 4253.

Date		h. m. s.
1883, Sept. 18		19 6 27.89
Oct. 1		28.63
3		28.07
5		27.81
Mean A. R. 1883.0		19 6 28.100

Radcliffe 4300.

Date		h. m. s.
1883, Aug. 8		19 15 39.05
11		38.95
Sept. 6		38.90
18		39.10
Oct. 1		38.79
3		38.65
Mean A. R. 1883.0		19 15 38.907

Radcliffe 4313.

Date		h. m. s.
1883, Aug. 8		19 16 48.50
11		48.96
Sept. 6		48.81
18		48.34
19		48.36
26		48.78
Mean A. R. 1883.0		19 16 48.538

τ Draconis.

Date		s.
1883, Oct. 5	B. J.	—0.32
9		—0.18
10		—0.08
11		—0.24
16		+0.01
	Mean	—0.162
	B. J.	47.807
		h. m. s.
Mean A. R. 1883.0		19 17 47.645

Groombridge 2900.

Date		s.
1883, Sept. 26	B. J.*	+0.18
27		+0.43
Oct. 1		—0.21
3		+0.20
9		+0.17
10		+0.40
11		+0.01
22		+0.33
	Mean	+0.189
		44.832
		h. m. s.
Mean A. R. 1883.0		19 28 45.021

* An ephemeris was computed from the data in the Jahrbuch.

MEAN RIGHT ASCENSIONS FOR 1883.0. — *Continued.*

Schwerd 1172.

Date		h. m. s.
1882, Oct. 21		19 30 2.72
26		1.99
1883, Mar. 1 s. p.		2.81
8 s. p.		3.05
13 s. p.		2.48
16 s. p.		2.69
21 s. p.		3.47
Sept. 5		2.46
6		2.43
19		2.33
21		2.73
Mean A. R. 1883.0		19 30 2.651

κ Cephei.

Date		s.
1883, Sept. 19	B. J.	+0.21
22		+0.34
Oct. 1		−0.22
3		+0.22
5		−0.11
22		−0.19
	Mean	+0.042
	B. J.	48.394
		h. m. s.
Mean A. R. 1883.0		20 12 48.436

Groombridge 3402.

Date		h. m. s.
1883, Mar. 18 s. p.		20 13 25.95
21 s. p.		27.78
29 s. p.		24.70
Apr. 2 s. p.		26.36
Sept. 15		27.35
Oct. 1		27.60
3		28.45
5		25.99
Mean A. R. 1883.0		20 13 26.772

Groombridge 3212.

Date		h. m. s.
1882, Oct. 7		20 16 18.57
30		18.20
31		18.42
Nov. 4		18.60
8		17.68
1883, Mar. 13 s. p.		17.97
23 s. p.		18.68
24 s. p.		18.92
28 s. p.		18.13
Sept. 15		18.44
19		18.24
22		18.38
Oct. 1		17.58
Mean A. R. 1883.0		20 16 18.289

Schwerd 1213.

Date		h. m. s.
1882, Oct. 30		20 21 4.36
31		4.17
Nov. 4		4.05
6		4.41
8		4.03
1883, Mar. 23 s. p.		4.23
24 s. p.		4.56
29 s. p.		4.07
Apr. 2 s. p.		4.19
Mean A. R. 1883.0		20 21 4.230

Groombridge 3260.

Date		h. m. s.
1882, Nov. 4		20 26 35.23
10		35.62
1883, Mar. 23 s. p.		35.52
24 s. p.		35.94
29 s. p.		35.17
Apr. 2 s. p.		35.21
Sept. 19		35.39
22		35.46
Oct. 1		35.16
3		35.47
Mean A. R. 1883.0		20 26 35.417

Groombridge 3261.

Date		h. m. s.
1883, Apr. 9 s. p.		20 30 0.79
10 s. p.		0.07
13 s. p.		0.24
14 s. p.		29 59.89
Oct. 3		0.31
5		0.33
22		0.49
Mean A. R. 1883.0		20 30 0.303

Bradley 2673.

Date		s.
1882, Sept. 15	A. E.	−0.09
16		+0.03
Oct. 7		+0.12
13		+0.14
1883, Sept. 15		+0.07
19		+0.25
22		+0.22
Oct. 1		+0.10
	Mean	+0.105
	A. E.	30.186
		h. m. s.
Mean A. R. 1883.0		20 30 30.291

MEAN RIGHT ASCENSIONS FOR 1883.0. — *Continued.*

Bradley 2701.

	h.	m.	s.
1882, Oct. 14	20	34	10.06
30			9.98
Nov. 4			9.73
6			9.68
1883, Mar. 13 s. p.			9.81
21 s. p.			10.08
23 s. p.			9.98
24 s. p.			10.44
Sept. 15			9.79
19			10.01
22			10.29
Oct. 1			9.60
Mean A. R. 1883.0	20	34	9.950

75 Draconis.

	h.	m.	s.
1882, Oct. 13	20	35	31.85
30			31.45
Nov. 4			31.26
6			31.40
1883, Mar. 13 s. p.			31.44
21 s. p.			31.82
23 s. p.			31.73
24 s. p.			32.38
Mean A. R. 1883.0	20	35	31.666

Schwerd 1235

	h.	m.	s.
1883, Apr. 13 s. p.	20	35	51.35
14 s. p.			51.11
Oct. 3			51.56
5			51.25
22			51.55
Mean A. R. 1883.0	20	35	51.364

74 Draconis.

	h.	m.	s.
1882, Sept. 15	20	36	10.29
16			10.79
Oct. 4			10.69
7			10.53
1883, Mar. 28 s. p.			10.47
29 s. p.			10.30
Apr. 2 s. p.			10.08
9 s. p.			10.65
Mean A. R. 1883.0	20	36	10.475

Radcliffe 4976.

	h.	m.	s.
1882, Oct. 4	20	40	39.63
7			39.59
13			39.90
14			39.82
1883, Mar. 28 s. p.			39.82
Apr. 6 s. p.			40.17
9 s. p.			40.53
10 s. p.			39.77
Mean A. R. 1883.0	20	40	39.904

Schwerd 1255.

	h.	m.	s.
1883, Nov. 7	21	0	26.91
8			26.97
16			26.94
17			26.95
19			27.02
Mean A. R. 1883.0	21	0	26.958

Schwerd 1258.

	h.	m.	s.
1883, Mar 22 s. p.	21	8	48.71
Apr. 2 s. p.			48.49
13 s. p.			48.63
14 s. p.			48.47
Oct. 18			48.75
Mean A. R. 1883.0	21	8	48.610

Schwerd 1260.

	h.	m.	s.
1883, Mar. 22 s. p.	21	11	44.48
Apr 2 s. p.			44.19
10 s. p.			44.90
13 s. p.			44.21
Nov. 5			44.21
7			44.18
8			44.34
16			44.18
Mean A. R. 1883.0	21	11	44.330

Radcliffe 5218.

	h.	m.	s.
1883, Mar 22 s. p.	21	17	20.73
Apr. 2 s. p.			20.56
9 s. p.			20.53
10 s. p.			20.68
Nov 8			20.41
16			20.67
17			20.65
19			20.36
Mean A. R. 1883.0	21	17	20.574

MEAN RIGHT ASCENSIONS FOR 1883.0. — *Continued.*

Radcliffe 5228.

		h. m. s.
1882, Oct. 14		21 18 9.23
21		9.38
Nov. 10		9.50
18		9.91
1883, Mar. 20	s. p.	10.23
Apr. 2	s. p.	9.74
13	s. p.	9.59
14	s. p.	9.79
Mean A. R. 1883.0		21 18 9.671

Groombridge 3548.

			s.
1882, Nov. 15		C. des T.	+0.12
16			—1.16
18			—0.28
20			—0.28
1883, Mar. 20	s. p.		—0.90
22	s. p.	[wt. = ½]	—1.02
Apr. 10	s. p.		—0.88
13	s. p.		—0.93
Oct. 16			—0.20
17			—0.65
18			—1.33
Nov. 5			—1.15
		Mean	—0.709
		C. des T.	46.40
			h. m. s.
Mean A. R. 1883.0			21 22 45.691

Bradley 2832.

		h. m. s.
1882, Nov. 20		21 22 53.69
21		53.30
1883, Mar. 20	s. p.	53.73
22	s. p.	53.82
Apr. 2	s. p.	53.49
9	s. p.	53.32
Nov. 7		53.46
8		53.39
27		53.11
28		53.00
Mean A. R. 1883.0		21 22 53.491

Groombridge 3511.

		h. m. s.
1882, Nov. 21		21 28 14.16
1883, Mar. 22	s. p.	14.20
Apr. 2	s. p.	14.00
9	s. p.	14.13
10	s. p.	14.36
Oct. 8		13.99
Nov. 7		13.98
8		14.00
19		14.10
Mean A. R. 1883 0		21 28 14.102

Cephei 32 H.

		h. m. s.
1883, Apr. 17	s. p.	22 22 27.68
Oct. 17		26.83
Nov. 27		26.24
28		26.81
Dec. 3		26.47
6		26.69
Mean A. R. 1883.0		22 22 26.703

Groombridge 3834.

		s.
1882, Dec. 9	A. E.	—0.11
1883, Oct. 17		—0.22
Dec. 6		—0.05
12		—0 28
	Mean	—0.165
	A. E.	12.987
		h. m. s.
Mean A. R. 1883.0		22 30 12.822

Piazzi XXII. 280.

	h. m. s.
1882, Nov. 4	22 50 18.83
10	20.00
16	19.55
Dec. 12 *	[20.98]
1883, Nov. 16	19.97
Mean A. R. 1883.0	22 50 19.588

* This observation is provisionally excluded: all the observations of this date are more or less doubtful, owing to the fact that one end of the axis was not properly fastened, and the value of *n* which is to be here applied is very uncertain.

MEAN RIGHT ASCENSIONS FOR 1883.0. — *Continued.*

Cephei 36 H.

	h. m. s.
1882, Oct. 20	22 55 17.85
28	17.51
Nov. 10	17.69
21	18.08
1883, Oct. 16	17.46
17	17.51
Nov. 16	17.81
Dec. 12	18.13
Mean A. R. 1883.0	22 55 17.692

o Cephei.

		s.
1882, Oct. 28	A. E.	+0.02
Nov. 16		−0.10
18		−0.01
21		−0.10
1883, Nov. 16		−0.09
	Mean	−0.056
	A. E.	49.567
		h. m. s.
Mean A. R. 1883.0		23 13 49.511

Cephei 39 H.

		s.
1882, Oct. 20	C. des T.	−0.88
28		−1.26
Nov. 4		−0.27
10		+0.44
1883, May 18 s. p.		+1.19
19 s. p.		−1.65
Oct. 15		+0.59

Cephei 39 H, — *continued.*

		s.
Nov. 16		−0.07
Dec. 12		+0.15
15		+0.72
21		+0.15
	Mean	−0.081
	C. des T.	50.31
		h. m. s.
Mean A. R. 1883.0		23 27 50.229

Groombridge 4163.

		s.
1882, Oct. 20	A. E.	−0.48
28		−0.08
Nov. 4		−0.41
10		−0.38
18		−0.39
1883, Oct. 15		−0.08
	Mean	−0.287
	A. E.	9.173
		h. m. s.
Mean A. R. 1883.0		23 49 8.886

Bradley 3194.

	h. m. s.
1882, Oct. 28	23 54 0.93
Nov. 4	1.42
10	1.50
18	1.09
1883, Oct. 15	1.70
Dec. 26	1.71
29	1.65
Mean A. R. 1883.0	23 54 1.429

CATALOGUE OF MEAN RIGHT ASCENSIONS FOR 1883.0.

Name of Star.	No. Obs.	Mean A. R. 1883.0.			Epoch.	Annual Precession.	Approximate Declination.	
		h.	m.	s.			°	′
Bradley 48	4	0	30	59.122	1883.9	+ 4.330	81	50.8
Bradley 74	6		44	0.495	1883.7	+ 5.172	83	4.3
Bradley 65	6		51	28.323	1883.7	+13.704	88	23.7
Bradley 95	4		56	38.390	1883.4	+ 8.453	86	31.3
38 Cassiopeiæ	4	1	22	32.547	1883.0	+ 4.343	69	39.7
Groombridge 339	4		36	54.928	1883.4	+11.683	86	21.2
Schwerd 75	4		44	2.060	1883.4	+19.212	87	55.2
Groombridge 424	5		55	4.912	1883.3	+ 7.017	80	44.1
Bradley 344	8	2	31	0.366	1883.3	+ 8.212	80	57.0
Groombridge 642	8	3	28	19.987	1883.2	+19.274	86	16.5
Groombridge 766	4	4	1	12.048	1883.6	+13.294	83	31.1
Groombridge 774	4		4	22.802	1883.6	+12.679	83	3.2
Groombridge 779	7		6	44.641	1883.0	+10.137	80	32.5
Groombridge 785	6		9	4.665	1883.4	+10.263	80	39.2
Radcliffe 1198*	7		16	12.719	1883.3	+10.351	80	37.3
Schwerd 241	4		17	29.715	1883.5	+14.144	83	47.2
Piazzi IV. 59	8		25	36.139	1883.3	+10.247	80	18.6
Piazzi IV. 77	8		28	37.021	1883.3	+10.377	80	25.6
Groombridge 848	5		33	6.516	1883.6	+ 7.954	75	43.5
Cephei 50 H.	8		38	30.224	1883.1	+10.981	80	59.8
Radcliffe 1311	6		50	27.600	1883.1	+20.457	85	48.2
Camelopardali 19 H.	9	5	3	17.922	1883.6	+ 9.799	79	5.6
Radcliffe 1377	5		4	13.934	1883.1	+19.806	85	34.0
Schwerd 306	4		7	32.792	1883.6	+14.973	83	45.4
Groombridge 966	6		24	5.011	1883.6	+ 7.988	74	57.8
Groombridge 944	6		24	37.782	1883.1	+18.588	85	8.0
Groombridge 1004	8	6	0	29.092	1883.1	+26.705	86	45.7
Schwerd 362	6		18	47.698	1883.5	+11.171	80	38.6
Schwerd 369	8		19	45.414	1883.4	+12.807	82	12.5
Schwerd 377	4		25	58.015	1883.6	+10.880	80	20.7
Camelopardali 23 H.	6		26	14.689	1883.7	+10.373	79	41.2
Camelopardali 24 H.	6		42	59.234	1883.7	+ 8.818	77	7.4
Groombridge 1255	8	7	3	6.902	1883.5	+11.646	81	28.0
Camelopardali 25 H.	14		6	23.397	1883.2	+12.981	82	38.0
Schwerd 406	5		9	10.546	1883.2	+16.169	84	26.0
Schwerd 415	5		11	25.706	1883.2	+12.397	82	13.8
Groombridge 1278	5		13	17.604	1883.7	+11.205	81	7.8
Schwerd 424	9		22	2.440	1883.5	+13.783	83	19.9
Camelopardali 28 H.	12		36	52.968	1883.3	+10.402	80	33.3
Groombridge 1119	12		38	44.02	1883.2	+71.047	88	58.6
Groombridge 1355	4		40	30.250	1883.7	+10.053	80	9.8
Groombridge 1368	9		46	20.127	1883.4	+ 9.715	79	47.8
Radcliffe 2020	6		46	45.597	1883.4	+20.293	86	1.9
Groombridge 1359	18		48	45.828	1883.3	+15.181	84	28.5
Groombridge 1391	11	8	1	46.863	1883.3	+12.182	82	47.4
Groombridge 1418	8		20	39.010	1883.0	+16.850	85	27.9
Groombridge 1431	8		25	6.781	1883.5	+11.427	82	39.0
Schwerd 529	8		38	31.751	1883.1	+11.655	83	9.5
Schwerd 533	8		41	15.820	1883.0	+11.607	83	11.3
Radcliffe 2218	9		50	44.090	1883.0	+13.562	84	38.9
Groombridge 1480	4		53	38.765	1883.3	+ 9.416	81	17.7
Schwerd 587	6	9	44	41.278	1883.6	+ 7.736	80	56.0
Radcliffe 2404	8		49	40.860	1883.6	+10.523	84	28.9
Radcliffe 2407	4		58	12.708	1883.4	+21.176	87	51.4

* Identical with Schwerd 242.

CATALOGUE OF MEAN RIGHT ASCENSIONS. — *Continued.*

Name of Star.	No. Obs.	Mean A. R. 1883.0	Epoch.	Annual Precession.	Approximate Declination.
		h. m. s.			° ′
Camelopardali 29 H.	12	10 12 26.892	1883.5	+ 9.775	84 50.7
Radcliffe 2594	6	11 0 18.173	1883.2	+14.507	88 16.5
Groombridge 1782	4	23 32.415	1882.8	+ 4.537	81 46.3
Groombridge 1850	4	58 50.642	1883.4	+ 3.175	86 14.1
Bradley 1656	5	12 13 25.256	1883.8	+ 1.535	87 5.2
Bradley 1672	11	14 20.60	1883.4	+ 0.172	88 20.9
Groombridge 1923	6	37 32.972	1883.4	+ 0.893	84 17.2
Groombridge 1927	7	41 27.780	1883.6	+ 1.507	81 15.8
Camelopardali 32 H.	14	48 16.332	1883.3	+ 0.391	84 2.9
Groombridge 2006	6	13 7 6.792	1883.	— 9.756	88 16.6
Groombridge 2007	8	19 22.211	1883.7	— 2.527	85 22.0
Groombridge 2063	5	45 43.634	1883.	— 2.024	83 20.4
Groombridge 2071	4	52 44.675	1883.	— 1.076	81 20.6
Groombridge 2099	9	14 1 28.637	1883.2	— 7.430	86 19.1
5 Ursæ Minoris	4	27 47.228	1883.5	— 0.203	76 13.0
Groombridge 2196	7	58 18.173	1883.3	— 4.560	82 59.5
Groombridge 2213	4	15 3 33.850	1883.3	— 6.723	84 24.2
Groombridge 2283	8	15 20.01	1883.3	—21.783	87 40.9
11 Ursæ Minoris	4	17 11.818	1883.5	— 0.094	72 14.9
Groombridge 2275	6	36 1.500	1883.	— 3.632	80 50.1
Groombridge 2276	6	36 14.158	1883.	— 3.637	80 50.2
Radcliffe 3445	4	37 2.932	1883.5	— 8.905	81 9.6
Schwerd 932	4	44 2.678	1883.5	— 3.915	80 59.1
Radcliffe 3475	4	45 22.802	1883.5	—10.207	85 12.6
18 Ursæ Minoris	5	46 6.074	1883.5	— 3.485	80 20.9
Schwerd 945	4	52 36.545	1883.5	— 4.337	81 17.2
Groombridge 2315	8	55 38.995	1883.3	— 6.672	83 17.9
A Draconis	5	16 28 13.109	1883.6	— 0.138	69 1.3
Schwerd 988	4	36 4.078	1883.5	— 8.710	83 57.1
Schwerd 986	4	38 53.132	1883.	— 4.062	80 1.9
Schwerd 1016	4	17 6 13.538	1883.6	— 5.160	81 1.5
Groombridge 2456	6	28 29.895	1883.4	— 4.625	80 14.3
Groombridge 2476	6	35 2.508	1883.4	— 8.460	83 25.6
ψ Draconis (S. Star)	7	44 1.462	1883.6	— 1.088	72 12.4
Schwerd 1059	4	51 26.282	1883.6	— 4.760	80 19.2
35 Draconis	7	54 41.368	1883.6	— 2.706	76 58.6
40 Draconis	4	18 8 47.685	1883.6	— 4.491	79 59.0
41 Draconis	6	8 58.892	1883.6	— 4.494	79 59.2
24 Ursæ Minoris	12	14 6.154	1883.5	—22.300	86 59.4
χ Draconis	18	23 9.947	1883.7	— 1.193	72 40.9
Radcliffe 3961	8	24 3.901	1883.4	— 5.743	81 25.4
Bradley 2412	12	39 34.600	1883.3	— 7.788	83 5.2
50 Draconis	4	50 8.524	1883.7	— 1.900	75 17.7
Radcliffe 4208	5	53 2.074	1883.0	—18.568	86 33.5
υ Draconis	6	55 49.637	1883.8	— 0.726	71 8.4
Radcliffe 4253	4	19 6 28.100	1883.8	— 8.612	83 44.6
Radcliffe 4300	6	15 38.907	1883.7	— 4.510	80 31.8
Radcliffe 4313	6	16 48.533	1883.7	— 4.514	80 33.0
τ Draconis	5	17 47.645	1883.8	— 1.087	73 8.8
Groombridge 2900	8	28 45.021	1883.8	— 8.521	79 22.0
Schwerd 1172	11	30 2.651	1883.3	— 7.335	83 14.0
κ Cephei	6	20 12 48.435	1883.8	— 1.915	77 21.5
Groombridge 3402	8	13 26.772	1883.5	—49.185	88 46.6
Groombridge 3212	18	16 18.289	1883.2	— 8.072	84 19.5

CATALOGUE OF MEAN RIGHT ASCENSIONS. — *Continued.*

Name of Star.	No. Obs.	Mean A. R. 1883.0.	Epoch.	Annual Precession.	Approximate Declination.
		h. m. s.			° ′
Schwerd 1213	9	20 21 4.230	1883.0	— 3.224	80 9.9
Groombridge 3260	10	26 35.417	1883.4	— 7.435	84 10.3
Groombridge 3261	7	30 0.303	1883.5	— 4.459	81 59.0
Bradley 2673	8	30 30.29	1883.2	— 0.213	72 8.1
Bradley 2701	12	34 9.950	1883.3	— 8.556	81 2.1
75 Draconis	8	35 31.666	1883.0	— 3.514	81 1.3
Schwerd 1235	5	35 51.364	1883.6	— 5.139	82 47.1
74 Draconis	8	36 10 475	1883.0	— 3.255	80 40.9
Radcliffe 4076	8	40 39.904	1883.0	— 5.518	83 13.1
Schwerd 1255	5	21 0 26.958	1883.9	— 5.193	83 29.3
Schwerd 1258	5	8 48.610	1883.4	— 2.464	80 41.2
Schwerd 1260	8	11 44.330	1883.6	— 2.304	80 32.5
Radcliffe 5218	8	17 20.574	1883.6	— 2.032	80 18.9
Radcliffe 5228	8	18 9.671	1883.0	— 2.248	80 44.4
Groombridge 3548	12	22 45.70	1883.3	—10.978	86 33.0
Bradley 2832	10	22 58.491	1883.4	— 4.673	83 45.8
Groombridge 3511	9	28 14.102	1883.5	— 1.596	80 0.9
Cephei 82 H.	6	22 22 26.703	1883.8	— 3.971	85 31.1
Groombridge 3834	4	30 12.821	1883.7	+ 1.081	75 37.4
Piazzi XXII. 280	4	50 19.588	1883.1	— 0.838	84 9.4
Cephei 86 H.	8	55 17.692	1883.8	— 0.312	83 43.2
o Cephei	5	23 13 49.512	1883.1	+ 2 427	67 28.3
Cephei 39 H.	11	27 50.264	1883.4	— 0.133	86 39.7
Groombridge 4163	6	49 8.886	1883.0	+ 2.855	73 45.6
Bradley 3194	7	54 1.420	1883.3	+ 2.567	86 3.3

In forming this catalogue the stars from the Berlin Jahrbuch were reduced to the fraction of the year *here* given by the proper motion from "Publication XIV. der Astronomischen Gesellschaft." For one star, χ Draconis, the true fraction .74 would have made a difference of some thousandths in the result.

For certain stars taken from the American Ephemeris, or its supplements, a similar course was followed. Those taken from the "Connaissance des Temps" were additionally corrected for omitted terms of some trifling importance in the nutation. They are, —

$$-0.00295 \sin (\odot + 82°.2)\ a$$
$$+0^s.009 \cos (\odot + 280°.9)\ b$$
$$-E$$

The first term, the only one at all sensible, is tabulated in the Annals of the Harvard College Observatory, Vol. IV., part 2, page xix.

The supposed annual proper motions thus eliminated for the stars of the American and French ephemerides are as follows: —

	s.		s.
88 Cassiopeiæ	+0.025	Groombridge 2283	+0.089*
Groombridge 944	+0.020	50 Draconis	—0.004
Camelopardali 25 H.	+0.009	Groombridge 3548	+0 043*
Groombridge 1119	—0.348*	Groombridge 3834	—0.001
Bradley 1672	—0.144*	o Cephei	+0.014
Camelopardali 32 H.	—0.012	Cephei 39 H.	+0.085
5 Ursæ Minoris	+0.005		

Where these proper motions are sensibly erroneous, usually too large, the true fractions of the year were employed; so that in no case will sensible error arise from employing the fractions to tenths only.

It is well known that the right ascensions of polar stars as determined by different astronomers seem to be affected by a different personal equation from equatorial stars. Thus, for instance, the stars determined by M. Gonnessiat, at Lyons, for 1883.0 (Comptes Rendus, for August 13, 1883) compare as follows with the right ascensions of the Berlin Jahrbuch and those of the present paper; G. denoting the Lyons observations, B. the values given by the Jahrbuch, and S. those here given.

	G.	B.	S.	B. — G.	S. — G.
	h. m. s.	s.	s.	s.	s.
Cephei 43 H.	0 52 57.60	57.87	....	+0.27	....
α Ursæ Minoris	1 15 51.92	51.88	....	—0.04	....
Groombridge 750	4 0 13.64	13.84	....	+0.20	....
Cephei 51 H.	6 45 16.28	16.79	....	+0.51	....
Groombridge 119	7 38 43.51	....	44.02	....	+0.51
Draconis 1 H.	9 20 18.30	18.31	....	+0.01	....
Bradley 1672	12 14 20.17	....	20.60	....	+0.43
Groombridge 2283	15 15 19.86	....	20.01	....	+0.15
ε Ursæ Minoris	16 57 59.49	59.85	....	+0.36	....
δ Ursæ Minoris	18 10 3.31	3.80	....	+0.49	....
λ Ursæ Minoris	19 41 1.43	2.28	....	+0.85	....
Bradley 2701	20 34 9.50	....	9.95	....	+0.45
Groombridge 3548	21 22 45.42	....	45.70	....	+0.28
Cephei 32 H.	22 22 26.11	....	26.70	....	+0 59
Cephei 39 H.	23 27 49.91	....	50.26	....	+0.35

The tendency to the positive sign, both in B. — G. and S. — G. is here unmistakable. If we assume (the propriety of this assumption might perhaps be questioned) that these values are mainly proportional to the secant of the declination, we shall have, —

* From the "Annales du Bureau des Longitudes."

	Decl.	$\Delta\alpha \cos\delta$ B.—G.		Decl.	$\Delta\alpha \cos\delta$ S.—G.
	°	s.		°	s.
Cephei 43 H.	85.63	+0.021	Groombridge 1119	88.98	+0.009
α Ursæ Minoris	88.69	—0.001	Bradley 1672	88.35	+0.012
Groombridge 750	85.25	+0.017	Groombridge 2283	87.68	+0.006
Cephei 51 H.	87.23	+0.025	Bradley 2701	81.04	+0 070
Draconis 1 H.	81.84	+0.001	Groombridge 3548	86.55	+0.017
ε Ursæ Minoris	82.23	+0.049	Cephei 32 H.	85.52	+0.046
δ Ursæ Minoris	86.61	+0.029	Cephei 39 H.	86.66	+0.020
λ Ursæ Minoris	88.95	+0 016			
Mean		+0.020±0.0038 s.	Mean		+0 026±0.0058 s.
P. E. 1 value		±0ˢ.0107	P. E. 1 value		±0ˢ.0154

So far as these observations go, there is no personal difference indicated with certainty between B. and S. I am, however, inclined to think that there may be a trifling one of the same order as that apparent; namely, S. — B. $= +0^s.005$ (with a probable error of $\pm 0^s.0069$ however); but I have not been able absolutely to prove its existence.

A somewhat plausible hypothesis, not usually adopted, is that for high northern declinations the ordinary probable error, due somewhat to the rapidity of the motion of equatorial stars, ceases to hold good. This hypothesis is somewhat favored by the fact that Bessel's time determinations with the Reichenbach circle differed from Struve's by a large amount, — more than one second; and that the difference between the right ascensions of Polaris and δ Ursæ Minoris, as determined by these two distinguished astronomers, seems to be due mainly to their clock corrections. In other words, they observed the polars alike, equatorial stars in an unlike manner.

On this theory M. Gonnessiat's clock corrections would be too small relatively to the Jahrbuch standard observer (Wagner) by $+0^s.33$; relatively to mine, by $+0^s.39$. After subtracting these numbers the remaining probable errors of one star, reduced to the equator, would be $\pm 0^s.013$ and $\pm 0^s.006$ respectively. The first number, however, would be reduced to a less quantity if the right ascension of Draconis 1 H. given in B. were corrected by the amount

$$+ 0^s.166 + 0^s.0097\,(\lambda - 1875),$$

which I have elsewhere indicated as probable; this value has been since very nearly confirmed by Pulcova observations for 1875.0 and 1880.0, which I owe to Vice-Director Wagner's kindness.

These values are, —

	M. Eq.	No. Obs.	A. R.	Correction to Publ. XIV.
			h. m. s.	s.
Wagner 1875.0	1875.0	12	9 19 5.967	+0.227
" 1880.0	1880.0	4	19 51.44	+0.284

Applying, then, the correction $+0^s.24$ to the Jahrbuch position for 1883.0, but adopting the first hypothesis, that the personal equation is directly proportional to sec. δ and overlooking the difference of equinox with G. altogether, we find

$$\begin{aligned} \text{B.} - \text{G. } \Delta\alpha \cos\delta \text{ (in mean)} &= +0^s.024; \\ \text{probable error of one star} &= \pm 0^s.010. \end{aligned}$$

On the second hypothesis, that the constant error is due to clock correction, but omitting its uncertainty in calculating the probable error, that is, multiplying the individual residuals by cos δ before calculating their sum of squares, we find

$$\text{B.} - \text{G. } (\Delta\alpha) = +0^s.36\text{; p. e. of one star } \epsilon \cos\delta = \pm\, 0^s.007.$$

For both B. — G. and S. — G. this hypothesis is rather more favorable than the other, but the evidence is yet far too scanty.

In fact, one object of the present publication is to induce the collection of more observations of these stars, and others at a somewhat greater distance from the pole. I find incidentally that a considerable portion of the stars of the present catalogue are now elsewhere in process of observation.

A form of personal equation has lately been noticed by Mr. Gill, which has some bearing here, — the difference in clock correction as the star seems to move eastward or westward. Of this I have as yet but trifling indications in my own case. As its cause is probably identical with that which makes it difficult to bisect an interval by the eye when the objects are at rest, it will have no more effect on the time of transit of a polar star than on that of an equatorial one, but will tend to produce difference (as Mr. Gill has found it to do) between the clock corrections from stars north and stars south of the zenith; it will also tend to produce difference between the resulting right ascensions of stars from observations above and below pole. This last difference I have found for these declinations to be imperceptible; but the half-difference of clock corrections is yet to be applied, as all my clock stars have been south of the zenith. So that the personal equations derived from this cause are probably either too small to be sensible in these declinations, or are merged in the form of personal equation discussed above.

The employment of Mr. Gill's reversing prism would perhaps be desirable in the continuation of this series.

The probable error of a single observation of a star within 10° of the north pole has been found to be rather less since the counterpoises were adjusted, in May; and a still further decrease has been indicated since the object-glass and eyepiece were exchanged in September. The illumination of the field, as before stated, has been more satisfactory.

I find from a great number of stars the following values reduced to the equator: —

	$\epsilon \cos \delta$.
1882 — 1883, April 17,	$\pm 0^s.0267$ (64 stars).
1883, May 9 — 1883, Dec. 31,	$\pm 0^s.0196$ (69 stars).

These values, however, are obtained by comparing observations in the same position of the instrument.

For the whole time I find by 49 stars the value

$$\epsilon \cos \delta = \pm 0^s.0238$$

from observations in two or three positions indifferently; a value which is very little larger than the average of the values which precede.

There are not enough stars beyond 10° from the pole to give an accurate value of the probable error, which in this region is somewhat increased; nor have I yet divided those within 10° into zones of declination.

From 46 stars observed since Sept. 5, 1883, only, I find

$$\epsilon \cos \delta = \pm 0^s.0161,$$

and it is quite possible that this smaller probable error may hold good for present and future observations, so long as the instrument remains in its present normal condition; the relative weights of the different periods will, however, be better discussed when more materials are available; and especially when a sufficient number of stars have been observed in four or more positions.

Another question deserves investigation: whether the personal equation for polar stars changes from time to time. I conceive, however, that the study of this point must at present be deferred. The simplest and best method to determine it will be to compare observations of successive whole years. I do not imagine that the reversal of object-glass and eyepiece would, by bringing into use new parts of the

pivots, produce a supposititious personal equation of this sort in a series of observations so entirely differential in character as the present; and the second complete year will not be finished till July, 1884.

In the attempt to compare the present observations with similar ones of earlier dates I was at once met with the difficulty arising from the lack of exact proper motions. The two early catalogues which are most available for their computation are Auwers's Bradley and Struve's Dorpat Observations of 1814–15. But I have not yet had time to complete the long calculations necessary for this purpose. The plan which I have formed is, first, to reduce to a fixed epoch all observations of these close polars which are free from dependence upon a meridian mark of the old fashion; omitting especially Fedorenko, Piazzi, Groombridge, and Pond, all of which require either large systematic corrections or frequent allowance for abnormal discrepancy. The better catalogues, without especial systematic correction, will give by least squares values of the proper motions, which will contain the personal equations, it is true, but the residual errors will afford some guide to their signs and amounts. The process would be analogous to that which Professor Newcomb has employed for standard right ascensions and Professor Boss for standard declinations; that is, in the least-square solution, one part of the chance errors for any given star is owing to the systematic error of the catalogues employed. It is of course impossible in this way to obtain the absolute values of the systematic corrections, and quite likely that the final results will not agree any better than if two catalogues, an old and a new one, were arbitrarily adopted as the basis for these corrections; but the method has at least the merit of exhibiting such discrepancies as really exist, and of showing what parts of the problem are for the time being absolutely insoluble. The observations of the next half-century are in fact necessary for its complete solution. It is my intention to continue these calculations, which have been long begun, and in which I have been assisted by one or two of my former pupils.

A rather serious stumbling-block in this matter, which will for a long time to come make it difficult to obtain exact reductions from one standard to another, and still more difficult to find a standard which is not in some degree arbitrary, lies in the relation between Bradley and Struve. For stars so near the pole as these, Bradley's observations give larger right ascensions than Struve's of 1814–15, so that, as Mädler has long ago pointed out, considerable positive reductions are needed to reduce the latter to the standard which he adopted, — the *Positiones Mediæ*. Whether this standard was held to

by him close enough is somewhat doubtful; there seems, however, to be no doubt that an interpolation between Bradley and the modern catalogues to the epoch of Struve's earlier work would give on the whole somewhat greater right ascensions of the stars of my list than Struve himself, even after the systematic corrections used by Argelander, which are derived from adopted positions of the clock stars, were applied.

In other words, the distribution of the early observations of any given polar is apt to be so irregular that any least-square solution will give somewhat uncertain results; and it will not be soon possible to arrange a really normal catalogue for these, any more than for other needed stars; a difficulty which in this case is aggravated by the small number of those objects in the critical positions which have been frequently enough observed.

A NEW THEORY OF COHESION APPLIED TO THE THERMODYNAMICS OF LIQUIDS AND SOLIDS.

By Harold Whiting.

Presented by invitation, March 12, 1884.

§ 1. The phenomena of surface tension, elasticity and latent heat prove that between the particles of matter, whatever they may be, there is an attraction which must be some function of the distance between them. It is this attraction against which work is done by expansion; and since work is the product of force and distance, we may obtain a measure of cohesion when we know the coefficient of expansion and the difference of the specific heats of a body under constant pressure and under constant volume.

The latter, unfortunately, in the case of solids and liquids, has not been accurately determined, so that this simple measure cannot be applied; but since the specific heat of liquids invariably exceeds that of their vapors at the same temperature, and the liquid coefficient of expansion is less, the cohesion in the liquid state must be much greater than in the state of vapor; and we may roughly calculate, in certain cases, the law of its variation.

We have, for instance, for boiling water, a specific heat of 42,000,000 ergs (C. G. S.), while that of steam, under constant volume, is 15,600,000 ergs, nearly; the difference being 26,400,000, and the coefficient of voluminal expansion of water at 100° being (apparently) .0007, a force of 38,000,000,000 dynes (C. G. S.) must be overcome in order to account for this work. The pressure of saturated steam is less than its calculated value,

according to Gay-Lussac, by from 600* to 5000 dynes.† The expansion into vapor being nearly equal to 1630 volumes of the boiling liquid shows that the cohesive attraction must have diminished between seven million and seventy million times, while the distance from particle to particle must have increased in the ratio of the cube root of 1630, or 11.75. In this case, therefore, we might infer that the cohesive attraction per unit of surface varied inversely as some power of the molecular distance not less than six and not greater than seven and one-half, a mean value being the most probable; and remembering that the number of particles which exert this attraction diminishes as the square of the distance increases, the molecular attraction would vary according to the fourth or fifth power, inversely.

For alcohol, in the same way, the coefficient of expansion at 78° being .0013, the total expansion into vapor about 455 volumes, and the difference of specific heats, 15,000,000 ergs, the cohesion is about 12,000,000,000 dynes per square centimetre, and since the pressure of the saturated vapor according to Gay-Lussac,‡ reduced by suitable formulae, is 15,000 dynes less than the theoretical value, it would appear that the molecular attraction varied as the four-and-two-thirds power, inversely.

For ether we find a difference of specific heats of only 4,000,000 ergs, and a coefficient of expansion .0017, indicating about 2,400,000,000 dynes for the cohesion; the expansion into vapor is about 235 volumes, and the pressure of cohesion of the vapor, deduced from Gay-Lussac's figures,§ is 14,000 dynes, also indicating the four-and-two-thirds power of the distance.

These are the only liquids which I can find, the density

* Allowing for the space occupied by the molecules. See Zeuner, Chap. I, III, Chaleurs latentes interne et externe.

† See Deschanel's Natural Philosophy, Part II. §283-284.

‡ See Zeuner, French Translation, 1869, page 282.

§ Zeuner, ibid.

of whose *saturated* vapors has been satisfactorily determined; and the indication is clearly that the cohesive attraction varies inversely as some power of the distance between four and five.

The constancy of this law may be established by comparing the tables for latent heats and surface tensions. The latter is easily seen, as Sir William Thomson and others have pointed out, to represent, numerically, a large fraction of the work necessary to volatilize a film of the thickness of one molecule; and neglecting this thickness, which does not vary through wide limits, we shall find that the surface tension and latent heat are approximately proportional. That is, not only the equivalent of the work necessary to separate a liquid into the thinnest possible laminae (or films) is approximately proportional to that necessary to volatilize it completely, but also both of these quantities are determined by the attraction of the molecules for each other, which could not be the case unless the law of variation of this attraction were the same, or nearly the same, for all liquids.

In no matter what way the cohesive pressure is calculated, we find that the latent heat varies very nearly in proportion; thus the total latent heat of steam is 536 units, of alcohol vapor 202 units, and of ether vapor 91 units, corresponding to the order of the cohesive pressures already calculated, and also to the order of their surface tensions, 81, 26 and 19 (dynes per centimetre).

These points will be more carefully considered after an analytical investigation of the actual relations which must subsist and those which probably subsist between these various quantities; at present all the evidence of the facts is to show that the cohesive attraction between two molecules varies as the fourth or fifth power of their distance, inversely, and not as any power materially greater or less.

There are various points of view which would make it seem improbable that any such general truth can be estab-

lished, and this accounts, undoubtedly, for the fact that the laws of cohesion have hitherto escaped a systematic investigation. These considerations will be met later on. It would seem, moreover, at first sight, that a multitude of solutions might be possible, each equally capable of explaining the various phenomena by means of a sufficient number of arbitrary assumptions — a number continually increasing, as new facts are discovered, until, like the corpuscular theory of light, the whole structure would fall as if by its own weight, under the blows of some simpler hypothesis.

Such is not the nature of the present investigation, which adds nothing to the assumptions already required by the molecular theory save one, which is shown to be the necessary consequence of various phenomena.

The object of this paper will be to investigate more fully the nature of the law of cohesion and to apply it to the solution of the relations existing between certain physical constants well known in thermodynamics. It may be stated that these have been generally viewed, hitherto, from a purely empirical standpoint.

§ 2. There are evidently three distinct pressures which exist in a liquid or solid: first, the external pressure (P); second, the kinetic pressure (P'), due to the vibration of the molecules; and third, the cohesive pressure (P''), due to the attraction of these molecules for each other. If these pressures are all expressed in the same unit (dynes per square centimetre), and are reckoned positively outwards, we have for a body in equilibrium the expression,

$$\overline{P} + P' + \overline{P}'' = 0,$$

the line drawn over P and P'' indicating that their true direction is inwards.

The rough investigation of § 1 is probably sufficient to show that in vapors, P'' in liquids and solids, P may generally be neglected; so that in vapors P and P', in liquids and solids, P'' and P' are very nearly equal and opposite. That is, in liquids and solids, the cohesive pressure plays the same part as does the external pressure in vapors.

The well-known formula connecting the volume, V, the pressure, P, and absolute temperature, T, of a gas,

$$\frac{PV}{T} = \text{constant},$$

or, in the form used largely in the kinetic theory,

$$PV = \frac{1}{3} Mv^2,$$

where M is the mass and v^2 the mean square of the molecular velocity, is established upon the assumption that the molecules of a gas are small as compared with the distance between them. If the molecule has any size, that is, if it prevents other molecules from approaching within certain definite limits, the free path (l) will in all cases be shortened by an amount (l') which I propose to call the molecular diameter. The present investigation proceeds on the usual hypothesis that the latter is nearly, at least, constant.

Since then the free path is shortened in the ratio of l to $l - l'$, the kinetic pressure will increase, *cæteris paribus*, in the same ratio, and we shall have for solids and liquids,

$$P'V = \frac{1}{3} Mv^2 \frac{l}{l-l}.$$

The kinetic theory asserts that two bodies are at the same temperature when their molecular kinetic energies are equal, that is, when

$$\frac{mv^2}{2} = \frac{m_1 v_1^2}{2},$$

and that furthermore

$$\frac{T}{T_0} = \frac{\frac{mv^2}{2}}{\frac{mv_0^2}{2}}$$

whence combining, and denoting by m_1 the mass of a hydrogen molecule, and by v_0^2 the mean square of its velocity at the freezing temperature of water ($T_0 = 273°$), we have, remembering that the density D is the quotient of M and V,

$$P' = \frac{1}{3} Dv_0^2 \frac{m_1}{m} \frac{T}{T_0} \frac{l}{l - l'}, \qquad \text{I.}$$

the fundamental formula in the kinetic theory of liquids and solids. If we suppose l' very small as compared with l, this formula immediately reverts to one of the forms well known in the theory of gases.

Let us now suppose that a body on being heated 1° expands freely by the small ratio ϵ; and that it is again compressed at constant temperature to its original volume. Designating by E the modulus of voluminal elasticity (after Maxwell), or *coefficient of resilience* (after Everett) under constant temperature, we shall require by definition an external pressure, $E\epsilon$, equal and opposite to the increase of internal pressure due to heat. The volume being unchanged, the density must be the same; and if there be no change in the molecular arrangement, the factor $l \div (l - l')$ must be unchanged; so that the only variable in equation I. is T, which has increased from a value, T, to the value $T + 1°$, thus causing an increase of the kinetic pressure equal to

$$\frac{1}{3} Dv_0^2 \frac{m_1}{m} \frac{1}{T_0} \frac{l}{l - l'} = \frac{P}{T} = E\epsilon,$$

from which we see that

$$E\epsilon T = P' = \frac{1}{3} Dv_0^2 \frac{m_1}{m} \frac{T}{T_0} \frac{l}{l - l'}, \qquad \text{II.}$$

that is, the continued product of the coefficients of voluminal elasticity and expansion with the absolute temperature is equal to the kinetic pressure.

This theorem applies only to liquids or solids in which no molecular rearrangement is brought about by heat or pressure, and which consequently agree, like gases, in obeying the same general laws of expansion. An examination of the tables will show that most liquids fall under this category. The most important exception is water, which we shall see, from many considerations, is not to be treated as a pure liquid, even at moderately high temperatures. In such liquids, l' may be treated as a variable, and there is no connection between the real and apparent compressibility and expansion.

The theorem is, in other respects, perfectly general, and gives, for gases (in which $\epsilon T = 1$ by the Law of Charles), $P' = E$, as it should be. The importance of the theorem, in determining readily the free path of a molecule and the measure of cohesion for liquids and solids, has apparently been overlooked. The application to liquids is restricted only by the paucity of those whose elasticity has been determined, and its extension only by our ignorance of the real nature of the law which governs molecular cohesion.

Let us therefore assume that the force between any two molecules in the line joining them varies as the xth power of their distance, inversely; then the component of this attraction in any direction will also vary as the xth power inversely; and if we conceive of a perfectly homogeneous and uniform expansion in which every line is increased in a certain ratio, called the ratio of linear expansion, so that the angles subtended by a particle are in no case altered, nor the direction of any line fixed in it, then the component of the attraction of every particle for every other, resolved in any one direction, will also vary as the xth power of the linear expansion, inversely, no matter how the

particles may be situated with respect to the common line of resolution; and hence the resultant force of cohesion, perpendicular to any surface, due to the action of all particles on one side of that surface upon all particles on the other, will also vary as the xth power, inversely, of the ratio of expansion, while the area of the surface separating a given number of molecules will vary inversely as the square of the ratio of expansion. It follows that the resultant cohesion P'', measured in dynes per square centimetre of surface, will vary inversely as the $x+2^{d}$ power of the ratio of linear expansion.

Denoting, therefore, by P_0'' the value of the cohesive pressure when the volume is V_0 and the average molecular distance l, we shall have

$$\frac{P''}{P_0''} = \frac{l_0^{x+2}}{l^{x+2}} = \frac{V_0^{\frac{x+2}{3}}}{V^{\frac{x+2}{3}}}$$

also, taking logarithms,

$$3 \log l - 3 \log l_0 = \log V - \log V_0$$

whence, by differentiation,

$$3\frac{dl}{l} = \frac{dV}{V}.$$

Now it is established in thermodynamics that the work δW done in the (small) expansion δV against the pressure P'' is

$$\delta W = P'' \delta V,$$

hence the total work necessary to overcome the cohesive forces in expanding from a volume V_1 to a volume V_2 will be

$$\Delta W = \int_{V_1}^{V_2} P' dV = P_0'' \int_{V_1}^{V_2} \left(\frac{V_0}{V}\right)^{\frac{x+2}{3}} dV.$$

If between the limits, V_1 and V_2, x can be regarded as constant and equal to a, we have

$$\Delta W = \frac{3}{a-1} P_0'' V_0^{\frac{a+2}{3}} \left(\frac{1}{V_1^{\frac{a-1}{3}}} - \frac{1}{V_2^{\frac{a-1}{3}}} \right)$$

whence if $V_0 = 1$ we may write

$$\Delta W = \frac{3}{a-1} P_0'' \Delta V^{\frac{1-a}{3}}$$

hence we have, for the total work required for completely vaporizing the unit of volume of a body, at constant temperature,

$$W = \Sigma \Delta W = \Sigma_{V=1}^{V=\infty} - \frac{3}{a-1} P_0'' \Delta \quad V^{\frac{1-a}{3}}.$$

It is easily seen that if a_2 be the maximum value of a, during expansion, and a_1 the minimum value, greater than 1,

$$W > \frac{3}{a_2 - 1} P_0''$$
$$< \frac{3}{a_1 - 1} P_0''$$

for, since V is necessarily greater than 1, each term in the series is greater than $\frac{3}{a_2 - 1} P_0'' \Delta V^{\frac{1-a_2}{3}}$ and less than $\frac{3}{a_1 - 1} P_0'' \Delta V^{\frac{1-a_1}{3}}$.

It follows that, independent of any theory of cohesion, if the force be known to vary inversely as some power of the molecular distance not greater in any case than a_2 and not less than a_1, the internal latent heat of vaporization of the unit of volume of any substance is known within two limits, in terms of the cohesive pressure P_0'', under which the substance exists in the original state.

Thus we have a mathematical proof of the statement in § 1, concerning the mutual dependence of latent heat and cohesion.

The possibility of such a connection, independent of the choice of units, is easily established by the consideration that the dimensions of work per unit of volume and pressure per unit of surface are the same, a consideration by which the discovery of some law like that alluded to might have been anticipated.

Denoting by a some value of the variable x between a_{I} and a_{II}, a value which, although perfectly definite in any case, is known only to lie within these limits, we have for the internal latent heat,* L, of the unit of volume, whose mass is D, the equation,

$$JLD = \frac{3}{a - 1} \; P_0'', \qquad \text{III.}$$

where J is the mechanical equivalent of heat, and remembering that $-\overline{P}_0'' = \overline{P} + P'$ we have, numerically,

$$JLD = \frac{3}{a - 1} \; (\overline{P} + P'),$$

where $\overline{P}$ may generally be neglected.

Combining with II. we have

$$JLD = \frac{3}{a - 1} (\overline{P} + E\epsilon T), \qquad \text{IV.}$$

an equation by which the value of a can be determined.

For a given value of a there will be an indefinite number of possible theories by which this value can be realized, but of this number one only is likely to be plausible. On the other hand, given any theory of the cohesive force, the value of a will be absolutely determined in every case, so that we shall be able at once to decide for or against the theory.

* The *internal* latent heat (which will be understood throughout this paper) is that necessary to convert the unit of weight of a substance into vapor of the same temperature without doing external work.

§ 3. The necessary data appear to have been determined only for the five liquids in the table: — *

	L	D	E		ϵ
Water	575.43	1.000	20.2	{ thousand million	— .00005
Alcohol	223.43	0.806 +	12.15	"	+ .00105
Ether	86.48	0.736	8.8?	"	+ .00150
Carbonic bisulphide	82.79	1.27	16.0	"	+ .00114
Turpentine	66. ?	0.89	13.7	"	+ .00071

$\mathcal{J} = 42{,}000{,}000. \quad T = T_0 = 273°$

The case of water must be thrown out for reasons already mentioned, which will be treated in full, later on.

We find for alcohol, $a = 2.38$; for turpentine, $a = 4.23$; for bisulphide of carbon, $a = 4.31$, and for ether $a = 5.04$. With the exception of alcohol, the numbers agree closely enough with those obtained from the rough calculation of § 1, although the latter were derived from the ratio of the cohesive forces in two widely different states of aggregation, while the values of a were determined by the work done against a cohesion continually decreasing during the change of state.

We are not able from these data to determine exactly what the law of cohesion is; but we are able to decide what it is not. Since a is a value intermediate between two values of x, namely a_1 and a_2, some values of x must be equal to or greater than a, and some values equal or less.

* With the exception of turpentine, the (internal) latent heats were from Zeuner's Tables (appendix); the densities from Wöhler's Organic Chemistry (indexed); the elasticity was the mean from Everett, pages 52 and 53 of his Units and Physical Constants; and the expansion is the mean of Kopp and Pierre. For turpentine, see Everett, page 88; Pickering's Physical Manipulation, Volume II., Appendix, Table 12; Ganot's Physics, § 334 and § 326.

Hence no force can explain the laws of cohesion which is not capable of varying, inversely, as a power of the distance which is greater in some cases than four at least, and less in others than $2\frac{1}{3}$. It would therefore appear that the law of universal gravitation, which requires a variation at great distances according to the inverse square, cannot explain the phenomena of cohesion; neither can any force which disappears completely in the state of vapor.

We have seen the conditions required by the considerations of the preceding sections. The only forces known to physics which can by any possibility satisfy them are those involving both attraction and repulsion, that is, polarity in some form.*

There is, however, a possibility of error in the result of any reasoning, no matter how many facts may have been gathered to support it; and in most minds there will be found an unwillingness to limit in any way the application of such a general truth as the law of universal gravitation, the beauty of which, if it could be adapted to the explanation of the laws of cohesion, would be admitted by all. It is to answer this objection, and to prove, once for all, that the law of universal gravitation can never explain the phenomena in question, that the following proof is added of a proposition which might be considered self-evident.

Let us suppose that the attraction between different particles varies inversely as the xth power of the distance; then the potential will vary inversely as the $x - 1^{st}$. The potential at the common centre of a series of nearly spheri-

* It is true that, in one sense, the law governing all forces, properly so called, is fundamentally the same, being reducible to elements attracting or repelling inversely as the square of the distance; nevertheless, in effect, forces are essentially different.

Two small systems of electrified points, neither being charged as a whole, will in general attract each other inversely as the fourth power of the distance. Small circular currents or electric vortices will do the same; and this is also the law for small magnets under certain conditions. (See Maxwell, Volume II., § 388.) Arranged in different ways, two particles of magnetized matter may attract inversely as the square, the fourth power, or again inversely as the seventh power of the distance; and the probable resultant of an indefinite number of such particles will be found to vary inversely as some power between the fourth and fifth of the average distance between them.

cal shells whose mean radii are proportional to the numbers 1, 2, 3, 4, etc., into which all the particles of a body may be considered as distributed in numbers proportional nearly to the squares of the radii, will be a constant multiplied by the series,

$$1 + \left(\frac{1}{2}\right)^{x-3} + \left(\frac{1}{3}\right)^{x-3} + \left(\frac{1}{4}\right)^{x-3} + \text{etc.},$$

or its equivalent as far as convergence is concerned. Now it is well known that, unless the exponent in this series were greater than unity, the series would not converge; accordingly the potential at any point would depend upon the whole quantity of surrounding matter, and not merely upon the nature and distribution of the substance in the immediate neighborhood; hence the latent heat would be governed, not only by the amount vaporized, but also by that which remained in the liquid or solid state. That is, a definite latent heat for a given substance would be impossible unless $x - 3 > 1$. We conclude that it is absolutely necessary that the attraction between different particles of a body, upon which latent heat depends, should vary, on the whole, inversely as some power of the distance greater than the fourth, so that this application of the law of universal gravitation must finally be abandoned.

A number of facts, based upon the variations of specific heat in the liquid state and the departures in gases from the Law of Boyle and Mariotte, might be brought forward to support the evidence already adduced; enough has probably been said to prove that if the phenomena are to be solved at all, it must be by some force which varies, for the most part, inversely as the fourth or fifth power of the distance.

§ 4. Having proved that a force of no other type can explain the phenomena arising from cohesion, it is now of

interest to inquire whether there are any known forces, similar to those of electric or magnetic action, which may be adequate to this task; and the following sections are accordingly devoted, for the most part, to the analytical investigation of the consequences of various suppositions.

The solution of problems in the theory of cohesion can only be obtained through some simple hypothesis; and the first which we shall examine is that the normal attraction of two particles is inversely as the fourth power of the distance. The investigation of the theory of cohesion from this point of view will be greatly facilitated by the study of the attraction and repulsion of small magnets, the laws for which are apparently identical with those which we have supposed.

Since any distribution of magnetism may be represented as the resultant of an indefinite number of very small magnetized particles, arbitrarily arranged, no matter what the shape of these particles may be,* I shall assume for convenience, in this investigation, that the ultimate particles of matter which need be considered are analogous to small uniformly magnetized spheres, which may or may not correspond to the chemical atoms. The correspondence, if any exist, will appear in this and in the next section.

The strength of field at any point, due to a uniformly magnetized sphere, may be represented by that due to a small magnet of equal moment at its centre;† hence the action of one magnetized sphere on another may be represented by that of a small magnet at the centre of the first upon the whole mass of the second sphere; but the action of the second sphere upon this small magnet would by the same proposition be equal to that of a second small magnet at its own centre; and therefore, since action and reaction are equal and opposite, two uniformly magnetized

* See Cumming, Theory of Electricity, Prop. I., page 225, et seq.
† See Cumming, Theory of Electricity, Prop. IX., page 276.

spheres must attract or repel exactly as two small magnets of respectively equal moments would do, if placed at their centres.

Since the field due to a small magnet is shown to vary in any direction inversely as the cube of the distance,* the attraction for a second small magnet, measured by the difference of the action upon the nearer and farther pole, will vary as the rate of change of a force, itself varying inversely as the cube of the distance, which rate of change is seen at once, by the principles of the calculus, to vary inversely as the fourth power of the distance.†

So long, therefore, as the atomic arrangement is not disturbed, whether a substance be elementary or compound, the attraction between any two atoms according to the analogy will vary, as we have supposed, inversely as the fourth power of the distance, and therefore, in the perfectly homogeneous expansion described in the last section, the value of x will be constant and equal to 4, so that we shall have

$$JLD = -P''. \qquad \text{I.}$$

If, however, the substance be not elementary, we must remember that, in the state of vapor, the spheres (or atoms), which we have supposed to be completely separated, must afterward be reunited in clusters, so that a part of the energy required to separate them completely will not be needed. An approximation to the relative amounts of energy required to volatilize an element and a compound, respectively, will be found by considering from how many atoms a given atom is separated in each case, and what attraction is exerted by each atom from which it is separated.

It is of course impossible to obtain an exact solution without knowing the atomic grouping, both in the solid

* Cumming, ibid.

† See Maxwell, § 388.

or liquid and in the gaseous state; but we know that it is impossible for a given atom to be surrounded by more than twelve at equal distances from it and from each other, and that, in order to have thirteen or more, some of the central distances must be increased. In any compact atomic arrangement, we shall therefore not commit a serious error by assuming that there are twelve atoms at unit-distance from a given atom, forty-eight at two units' distance, and in general $12\,n^2$ at n units' distance.

Not knowing how these atoms may be arranged, we must apply the theory of probabilities to determine the potential at any centre due to all the surrounding atoms; and we shall find that this potential, like the probable error of the mean of a number of terms, is proportional to the square root of that number; n^2 atoms at n units' distance will therefore through interference have a probable effect only as great as n atoms combined; and since the potential must vary, *cæteris paribus*, inversely as the cube of the distance, the effect of $12\,n^2$ atoms at n units' distance, as in the case of an indefinite number of magnetized particles, will be equal to that at unit-distance of 12 atoms divided by n^2. The whole number of atoms surrounding a given atom will therefore be equivalent, very nearly, to

$$12\left(1 + \frac{1}{2^2} + \frac{1}{3^2} + \frac{1}{4^2} + \text{etc.}\right)$$

atoms at unit-distance.

This series may be broken up into two, namely,

$$1 + \frac{1}{3^2} + \frac{1}{5^2} + \frac{1}{7^2} + \text{etc.},$$

which is shown* to be equal to $\frac{\pi^2}{8}$, and a second series,

* Riemann's "Partielle Differentialgleichungen," § 23, fin.

$$\frac{1}{2^2} + \frac{1}{4^2} + \frac{1}{6^2} + \frac{1}{8^2} + \text{etc.},$$

which is easily seen to be one-fourth of the original series. Since, then, three-fourths of the series is equal to $\frac{\pi^2}{8}$, the whole series is equal to $\frac{\pi^2}{6}$.

We see, therefore, that the theory which we are investigating is not open to the criticism which caused us to abandon the theory of gravitation, since the potential, which determines the latent heat, is practically independent of the whole mass of a substance, provided only that it contain several layers of molecules or atoms, as we always suppose it to do.

The latent heat is the same as if about $2\,\pi^2$ atoms could surround a given atom, and for convenience in rough calculation we may call this number twenty.

It follows that a substance having two atoms in the molecule will require about one-twentieth less heat to volatilize it than if it had only one, since in the latter case each atom is practically separated from twenty others (whose interference may be neglected), while, in the former, one of these remains by its side. In the same way, if the molecule contain three or four atoms, clustered, the substance will require two- or three-twentieths less heat respectively; but when there are more than two atoms in the molecule, we may have a variety of atomic groupings possible, and to obtain even a rough measure of the latent heat, a knowledge of the graphical symbol will be necessary.

If the atoms be of different kinds, the solution becomes still more complex, and indeed impossible in the present state of our knowledge of the molecular constitution.*

* See, however, Rühlmann, Mechanischen Wärmetheorie, Volume II., page 226 et seq.

A special device must be invented for approximation in each particular case; and although a solution of this sort is of course worthless for purposes of demonstration, it will be sufficient to show whether the facts are satisfied or not by the theory within reasonable limits, and if the error, introduced by the complexity of a molecule in a given case, is found to be small as compared to the whole quantity, we may suppose that any small mistake in the elimination of this error will have still less influence in the result.

We have reason to expect, à priori, that in any simple liquid the latent heat will be less than its uncorrected value by not more than fifty per cent.; and if we allow for a mistake of even twenty per cent. in calculating the correction, we ought not to be in error by more than ten per cent. in the result.

When the latent heat has been determined, we ought to be able to supply either the elasticity or the coefficient of expansion, with the same degree of approximation, wherever formula II. of § 2 applies. If a liquid be not simple, but compounded (chemically) of two, differing widely in their properties, especially if the union be not very intimate, we may shorten the calculation by treating the compound liquid as a mechanical mixture of its components. Thus ethyl hydrate (alcohol) may be treated as a mixture of 18 parts water and 74 parts ethyl oxide (ether), whereas the latter (ethyl oxide) would not be treated as a mixture of ethylene and water, even if we possessed the necessary data.

§ 5. In applying the rules and formulae of the preceding sections, it must be remembered that they were established on the assumption, which has not so far been questioned, that the ultimate atoms are perfectly elastic,

but nevertheless sufficiently hard to resist any change of shape induced by the sudden pressure of impact. In the case of gases and vapors, it is known that this yielding may be disregarded; but in liquids and solids we have no right to assume that the laws founded upon this assumption will be rigorously true. It must not be attempted, without a special examination, to apply them to mercury, or any substance whose coefficient of expansion is so widely different from that of a gas. A cursory glance at the tables of expansion will be sufficient, however, to show that the densest bodies have, in general, the least coefficients of expansion, so that the existence of such substances as mercury and the heavy metals, with their very small coefficients, encourages us to think that in such light and expansible liquids as ether, alcohol, etc., there may still be sufficient distance between the molecules to enable us to disregard their compressibility.

The ratio of the two products, JLD and $E\epsilon T$, which should be unity for an elementary substance containing only one atom to the molecule, I shall call the *principal ratio*. This ratio has not been determined for a single elementary substance.

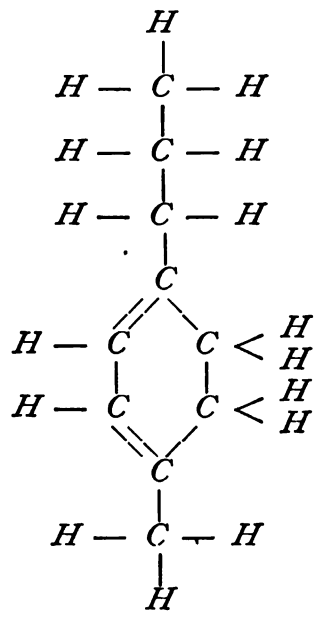
From the mean results tabulated in § 3, we find for the principal ratio of alcohol the value 2.17; for ether, 0.74; for bisulphide of carbon, 0.89, and for turpentine, 0.93. These numbers are not probably accurate within five or even ten per cent., as two determinations of the modulus of elasticity alone are apt to differ by ten or twelve per cent.

For bisulphide of carbon, we may adopt the graphical symbol $S = C = S$, the symbol $\begin{array}{c} S = S, \\ \backslash\backslash\ // \\ C \end{array}$ or $\begin{array}{c} S \equiv S. \\ \backslash\backslash\ // \\ C \end{array}$

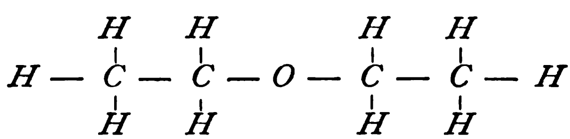
We shall find, in either case, one atom of carbon united to two atoms of sulphur; but in the first case the two sul-

phur atoms are attached only on one side, in the others there are two points of attachment, indicating clearly for each atom a loss of $\frac{2}{20}$ of the maximum value of the latent heat, that is, a principal ratio of 0.90; but the first case indicates for two atoms the value 0.95 and for one the value 0.90, giving an average value anywhere from 0.91 to 0.94 according as we take the numbers of atoms, merely, or the atomic weights into account.

In the same way, for turpentine, assuming the graphical symbol



or some different symbol, more or less condensed,* we have for the principal ratio a set of values from 0.83 to 0.90, and for ether



we have values from 0.84 to 0.91.

* See Beilstein, Vol. II., page 1769.

In all these cases the attraction only of the atoms in direct union with a given atom is taken into account.

The calculated and observed values of the principal ratio are compared as follows:

	Calculated.	Observed.
Bisulphide of Carbon . . .	0.90 to 0.94	0.89
Turpentine.	0.83 to 0.90	0.93
Ether	0.84 to 0.91	0.74

where it will be noticed that the calculated and observed values agree almost within the limit of probable error of the latter, according to a statement already made.

It was pointed out in the last section that a liquid might in some cases be treated as a mechanical mixture of two of its components, if the properties of these components were known.

We have for a mechanical mixture of A volumes of a liquid whose properties are designated by a prime ($'$), and B volumes of a liquid designated by two primes ($''$), the equations,

$$L = \frac{AL' + BL''}{A + B}$$

$$D = \frac{AD' + BD''}{A + B}$$

$$\epsilon = \frac{A\epsilon' + B\epsilon''}{A + B}$$

$$E = \frac{A + B}{\frac{A}{E'} + \frac{B}{E''}}$$

so that, if $A + B = 1$, we have

$$\frac{JLD}{E\epsilon T} = \frac{J\,(AL' + BL'')\,(AD' + BD'')}{\frac{E'E''}{AE'' + BE'}\quad (A\epsilon' + B\epsilon'')\,T},$$

in which formula we see that even if both liquids A and B satisfy the equations,

$$JL'D' = E'\epsilon' T, \text{ and } JL''D'' = E''\epsilon'' T,$$

it will not in general be true that a mixture of the two liquids will do the same.

Treating alcohol as a mixture of ether and water we have, from the table in § 3, since

$$A = \frac{74}{92} \text{ and } B = \frac{18}{92},$$

the value 1.86 indicated* for the principal ratio, at 0° centigrade, against 2.17 observed.

Independent of the theory, from a mechanical point of view, it may be interesting to note the values of the separate quantities indicated, namely: for the latent heat, 182, which is correct at 100° according to Zeuner; for the density, .787, which is true at about 25°; for the modulus of elasticity, 9,899,000,000, which would probably be right in the neighborhood of 35° (see Everett, page 52); and for the coefficient of expansion, .001196, which is the value at about 45° according to Pierre.

It is not inconsistent with the modern theories of molecular structure to suppose that those parts of different molecules which may have greater mutual cohesion than the rest should be drawn together so as to form a nucleus; and it is possibly the clustering of the "*hydroxyl*" radicals, in alcohol, which enables us to treat it so successfully as a mixture of ether and water. On the other hand, it is the impossibility, perhaps, of the formation of such nuclei that causes the approximate agreement of the first three liquids with the theory for elementary substances.

The investigation of the case of water, which alone remains, will be deferred until after the analytical treatment of

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$$* \frac{JLD}{E\epsilon T} = \frac{42{,}000{,}000\left(\frac{74}{92}\,86.5 + \frac{18}{92}\,575\right)\left(\frac{74}{92}\,0.736 + \frac{18}{92}\right)}{\dfrac{20{,}200{,}000{,}000 \times 8{,}800{,}000{,}000}{\frac{74}{92}\,20{,}200{,}000{,}000 + \frac{18}{92}\,8{,}800{,}000{,}000}\left(\frac{74}{92}\,0.0015 - \frac{18}{92}\,0.00005\right) \times 273}$$

the coefficients of elasticity and of expansion; we shall find no reason to regard it as an exception to our fundamental laws.

In conclusion I would say that too much weight must not be attached to the accidental agreement of the three liquids tabulated, it being not very improbable that a fourth liquid should differ by a hundred per cent. from the value calculated in the same way. The case of alcohol is a good example, which has been explained. In dealing, however, with such large numbers as the elasticity and mechanical equivalent, and such small ones as the coefficient of expansion, the slightest mistake *in the formulae* would be apt to increase or diminish the result by hundreds or perhaps millions of times; and even an approximate agreement between theory and observation must, in such cases, be considered in the light of a confirmation.

In the case, therefore, of the element bromine, the symbol being Br_2, I will venture to predict that the principal ratio will be found to be equal, very nearly, to 0.95. Since the total latent heat at 63° is given as 45.6 (Andrews), and the density 3.187 (Cooke), the coefficient of expansion at zero is .001038 (Pierre), and since the internal latent heat at 0° is 46.0,* we have

$$E = \frac{42{,}000{,}000 \times 46.0 \times 3.187}{0.95 \times .001038 \times 273} = 22{,}870{,}000{,}000,$$

the same, nearly, as for water at 41° (Jamin), which value is therefore predicted for the coefficient of resilience of bromine to hold within the ordinary limits of errors of observation.

§ 6. If in the equation of equilibrium,

$$\bar{P} + P' + \bar{P}'' = 0,$$

* Calculated by the usual formulae, assuming the absolute vapor density to be .007168 (reduced to 0° centigrade and 1,014,200 dynes pressure); also using the specific heats of the liquid and vapor as determined by Regnault.

we substitute the value of P' in terms of P_0' derived from equation I. § 2, namely,

$$\frac{P'}{P_0'} = \frac{T}{T_0}\,\frac{D}{D_0}\,\frac{l_0 - l'}{l_0}\,\frac{l}{l - l'} = \frac{T}{T_0}\,\frac{l_0^2\,(l_0 - l')}{l^2\,(l - l')},$$

since the density varies inversely as the cube of any length, and if, moreover, we substitute the value of P'' in terms of P_0'',

$$\frac{P''}{P_0''} = \frac{l_0^6}{l^6},$$

as required by our hypothesis for bodies suffering no change of state, we have

$$\overline{P} + P_0'\,\frac{T}{T_0}\,\frac{l_0\,(l_0 - l')}{l^2\,(l - l')} + \overline{P}_0''\,\frac{l_0^6}{l^6} = 0.$$

Differentiating with respect to log V, and remembering that, since $V : V_0 = l^3 : l_0^3$,

log V — log V_0 = 3 log l — 3 log l_0, whence differentiating, $\frac{dV}{V} = \frac{3dl}{l}$, we have

$$V\,\frac{d\overline{P}}{dV} + \frac{l}{3}\,\frac{dP'}{dl} + \frac{l}{3}\,\frac{d\overline{P}''}{dl} = 0, \text{ that is,}$$

$$V\,\frac{d\overline{P}}{dV} - \frac{l}{3}\,P_0'\,\frac{T}{T_0}\,\frac{l_0^2\,(l_0 - l')\,(3l^2 - 2ll')}{l^4\,(l - l')^2}$$

$$- \frac{l}{3}\,\frac{P_0'}{T_0}\,\frac{l_0^2}{l^2}\,\frac{(l_0 - l')}{(l - l')}\,\frac{VdT}{dV} - 6\,\frac{l}{3}\,\overline{P}_0''\,\frac{l_0^6\,l^5}{l^{12}} = 0.$$

Simplifying, and substituting P' and P'' in place of their values, also putting $\overline{P} + P'$ in place of $-\overline{P}_0''$, we have

$$V\,\frac{d\overline{P}}{dV} - \frac{P'}{3}\left(\frac{4l' - 3l}{l - l'}\right) + P'\,\frac{V}{T}\,\frac{dT}{dV} + 2\overline{P} = 0. \text{ I.}$$

In this formula, if we suppose T constant, that is if $\frac{dT}{dV} = 0$, we find

$$V\frac{d\overline{P}}{dV} - \frac{P'}{3}\left(\frac{4l' - 3l}{l - l'}\right) + 2\,\overline{P} = 0;$$

but the coefficient of resilience, E, being defined as the limit of the numerical ratio of the increment of external pressure $(\delta\overline{P})$ to the corresponding voluminal compression, $\left(\frac{\delta V}{V}\right)$, the temperature being constant, is equal algebraically to the first term $V\frac{d\overline{P}}{dV}$; hence we have

$$E = \frac{P'}{3}\left(\frac{4l - 3l'}{l - l'}\right) - 2\overline{P}. \qquad \text{II.}$$

Now if in I. we suppose the pressure to be constant, that is if $\frac{dP}{dV} = 0$, we shall have, transposing and inverting,

$$\epsilon = \frac{dV}{VdT} = \frac{P'}{T\left(\frac{P'}{3}\left(\frac{4l' - 3l}{l - l'}\right) - 2\overline{P}\right)} \qquad \text{III.}$$

since ϵ is defined as the coefficient of voluminal expansion under constant pressure.

The truth of the formulae II. and III. is easily tested by multiplying them together. We have

$$E\epsilon = \frac{P'}{T},$$

a relation already established by mechanical considerations (§2).

If, moreover, in III., we put $\frac{l'}{l} = 0$, and $P + P' =$

$-P'' = 0$, that is, if we express the two conditions always assumed to hold in perfect gases, we shall have

$$\epsilon = \frac{1}{T}$$

as should be the case.*

Substituting this value in the last equation, we find $E = P$,' which is easily shown to hold for perfect gases.

There is, therefore, every reason for confidence in the formulae of this section, the applications of which will be treated of when the ratio of l' to l has been determined.

The next and several following sections will be devoted to the relations which exist between the coefficients (E and ϵ) and their derivatives, which, we shall find, can be established independent of the value of $l' \div l$. It is sufficiently obvious, from the preceding investigation, that some such relations must exist; nevertheless these have not been studied, and have been known only empirically hitherto.

It is commonly supposed that in the experimental data for the expansion of liquids, or those at least which have been studied the most, little remains to be desired; such, however, is not the case, as may easily be seen by comparing the results of different observers. There is probably no branch of physics in which the accuracy attainable has been so far overestimated. Had the real uncertainty of the determinations been recognized, the theoretical bearings would undoubtedly have claimed more attention.

§ 7. To investigate the laws of a liquid or solid, expanding freely under heat, we put $\bar{P} = 0$ in equation III. of the last section, which then becomes

$$\epsilon = \frac{3}{T} \frac{l - l'}{4l' - 3l} \qquad \text{I.}$$

* It may here, for convenience, be pointed out that ϵ must not be confounded with the *absolute* coefficient of expansion, being defined approximately as the *ratio* of increase of volume to the volume itself for a rise of 1° in temperature. The difference, which is considerable for gases, in the case of liquids and solids will be found to be slight.

whence, by differentiation with respect to T,

$$\frac{d\epsilon}{dT} = -\frac{l-l'}{4l'-3l} \times \frac{3}{T^2} + \frac{3}{T}\left(\frac{(4l'-3l)+3(l-l')}{(4l'-3l)^2}\right)\frac{dl}{dT}$$

$$= -\frac{\epsilon}{T} + \frac{3}{T}\left(\frac{1+\epsilon T}{4l'-3l}\right)\frac{dl}{dT},$$ from I., and substituting

for $\frac{dl}{dT}$ its value, $\frac{\epsilon l}{3}$ (see last section), we have

$$\frac{d\epsilon}{dT} = -\frac{\epsilon}{T} + \frac{\epsilon l}{T(4l'-3l)} + \frac{\epsilon^2 l}{4l'-3l}$$

$$= \frac{\epsilon}{T}\left(\frac{4(l-l')}{4l'-3l}\right) + \frac{\epsilon^2 l}{4l'-3l},$$

hence again from I.

$$\frac{d\epsilon}{dT} = \frac{4\epsilon^2}{3} + \frac{\epsilon^2 l}{4l'-3l} = \frac{4\epsilon^2}{3} + \frac{\epsilon^2}{4\frac{l'}{l}-3}.$$

Now from I. we have

$$4l'\epsilon T - 3l\epsilon T = 3l - 3l';$$

$$l'(4\epsilon T + 3) = l(3\epsilon T + 3);$$

$$\frac{l'}{l} = \frac{3+3\epsilon T}{3+4\epsilon T}; \qquad \text{I.}a.$$

which, substituted in the preceding equations, gives

$$\frac{d\epsilon}{dT} = \frac{4}{3}\epsilon^2 + \frac{\epsilon^2}{\frac{12+12\epsilon T}{3+4\epsilon T}-3} = \frac{4}{3}\epsilon^2 + \frac{\epsilon^2(3+4\epsilon T)}{3}$$

$$= \frac{4}{3}\epsilon^2 + \epsilon^2 + \frac{4}{3}\epsilon^3 T,$$ so that, finally,

$$\frac{d\epsilon}{dT} = \frac{7}{3}\epsilon^2 + \frac{4}{3}\epsilon^3 T, \qquad \text{II.}$$

a relation between ϵ and its first derivative which is independent of the value of l or l'.

Differentiating again, we find

$$\frac{d^2\epsilon}{dT^2} = \frac{14}{3}\epsilon\frac{d\epsilon}{dT} + 4\epsilon^2 T\frac{d\epsilon}{dT} + \frac{4}{3}\epsilon^3$$

where, substituting the value of $\frac{d\epsilon}{dT}$ in terms of ϵ, we have

$$\frac{d^2\epsilon}{dT^2} = 12.\dot{2}\epsilon^3 + 15.\dot{5}\epsilon^4 T + 5.\dot{3}\epsilon^5 T^2. \qquad \text{III.}$$

In the same way, by successive differentiation and substitution of the values of the first derivative in terms of ϵ, we have

$$\frac{d^3\epsilon}{dT^3} = 101.11\epsilon^4 + 204.74\epsilon^5 T + 145.19\epsilon^6 T^2 + 35.55\epsilon^7 T^3, \qquad \text{IV.}$$

accurate to two places of decimals, and

$$\frac{d^4\epsilon}{dT^4} = 1148.\epsilon^5 + 3218.\epsilon^6 T + 3504.\epsilon^7 T^2 + 1743.\epsilon^8 T^3 + 332.\epsilon^9 T^4, \qquad \text{V.}$$

where the coefficients are expressed to the nearest unit; so that when ϵ is given, the values of its successive derivatives at any temperature are determined.

At the end of this paper will be found a table (I.) showing the corresponding values of ϵ and its first four derivatives at the freezing temperature of water ($T_0 = 273°$), from $\epsilon_0 = .0001$ to $\epsilon_0 = .002$. Tables may easily be constructed for any temperature; the use of this particular table is explained below.

Let the volume (V) of a liquid which is unity when the temperature is 0° centigrade ($t = 0$) be represented by a sufficient number of coefficients in the form,

$$V = 1 + at + bt^2 + ct^3 + dt^4 + et^5 + \text{etc.};$$

then the absolute coefficient of expansion will be expressed by the series,

$$a + 2bt + 3ct^2 + 4dt^3 + 5et^4,$$

so that the voluminal expansion, ϵ, which is the quotient of the absolute expansion by the volume, will be

$$\epsilon = \frac{a + 2bt + 3ct^2 + 4dt^3 + 5et^4 + \text{etc.}}{1 + at + bt^2 + ct^3 + dt^4 + et^5 + \text{etc.}}$$

whence, by actual division, we find

$$\begin{aligned} \epsilon = a + (2b - a^2)\, t + (3c - 3ab + a^3)\, t^2 \\ (+4d - 4ac - 2b^2 + 4a^2b - a^4)\, t^3 \\ + (5e - 5ad - 5bc + 5a^2c + 5ab^2 - 5a^3b + a^5)\, t^4 \\ + \text{etc.} \end{aligned} \qquad \text{VI.}$$

Putting a', b', c', d' and e' in place of the coefficients of the successive powers of t, so that

$$\left.\begin{aligned} a' &= a \\ b' &= 2b - a^2 \\ c' &= 3c - 3ab + a^3 \\ d' &= 4d - 4ac - 2b^2 + 4a^2b - a^4 \\ e' &= 5e - 5ad - 5bc + 5a^2c + 5ab^2 - 5a^3b \\ &\quad + a^5 \end{aligned}\right\} \text{VII.}$$

we have .

$$\left.\begin{aligned} \epsilon &= a' + b't + c't^2 + d't^3 + e't^4 + \text{etc.} \\ \frac{d\epsilon}{dt} &= b' + 2c't + 3d't^2 + 4e't^3 + \text{etc.} \\ \frac{d^2\epsilon}{dt^2} &= 2c' + 6d't + 12e't^2 + \text{etc.} \\ \frac{d^3\epsilon}{dt^3} &= 6d' + 24e't + \text{etc.} \\ \frac{d^4\epsilon}{dt^4} &= 24e' + \text{etc.} \\ \frac{d^5\epsilon}{dt^5} &= 0 + \text{etc.} \end{aligned}\right\} \text{VIII.}$$

Hence, substituting, we have

$$\frac{d^3\epsilon}{dt^3} = 6d' = t\,\frac{d^4\epsilon}{dt^4} \text{ etc., } or\ d' = \frac{1}{6}\,\frac{d^3\epsilon}{dt^3} - \frac{t}{6}\,\frac{d^4\epsilon}{dt^4} + \text{etc.}$$

$$\frac{d^2\epsilon}{dt^2} = 2c' + t\,\frac{d^3\epsilon}{dt^3} - t^2\,\frac{d^4\epsilon}{dt^4} + \frac{t^2}{2}\,\frac{d^4\epsilon}{dt^4} + \text{etc.}$$

$$= 2c' + \frac{td^3\epsilon}{dt^3} - \frac{t^2}{2}\,\frac{d^4\epsilon}{dt^4} + \text{etc.,}$$

whence $\displaystyle c' = \frac{1}{2}\,\frac{d^2\epsilon}{dt^2} - \frac{t}{2}\,\frac{d^3\epsilon}{dt^3} - \text{etc.}$

$$\frac{d\epsilon}{dt} = b' + t\,\frac{d^2\epsilon}{dt^2} - t^2\,\frac{d^3\epsilon}{dt^3} + \frac{t^3}{2}\,\frac{d^4\epsilon}{dt^4} + \frac{t^2}{2}\,\frac{d^3\epsilon}{dt^3}$$

$$- \frac{t^3}{2}\,\frac{d^4\epsilon}{dt^4} + \frac{t^3}{6}\,\frac{d^4\epsilon}{dt^4} - \text{etc.,}$$

whence

$$b' = \frac{d\epsilon}{dt} - t\,\frac{d^2\epsilon}{dt^2} + \frac{t^2}{2}\,\frac{d^3\epsilon}{dt^3} - \frac{t^3}{6}\,\frac{d^4\epsilon}{dt^4} + \text{etc.,}$$

and finally

$$\epsilon = a' + t\,\frac{d\epsilon}{dt} - t^2\,\frac{d^2\epsilon}{dt^2} + \frac{1}{2}\,t^3\,\frac{d^3\epsilon}{dt^3} - \frac{t^4}{6}\,\frac{d^4\epsilon}{dt^4}$$

$$+ \frac{t^2}{2}\,\frac{d^2\epsilon}{dt^2} - \frac{t^3}{2}\,\frac{d^3\epsilon}{dt^3} + \frac{t^4}{4}\,\frac{d^4\epsilon}{dt^4} + \frac{t^3}{6}\,\frac{d^3\epsilon}{dt^3}$$

$$- \frac{t^4}{6}\,\frac{d^4\epsilon}{dt^4} + \frac{t^4}{24}\,\frac{d^4\epsilon}{dt^4} + \text{etc.,}$$

from which the value of a' can be determined.

Summing up our results, we have

$$\left.\begin{aligned}
a' &= \epsilon - t\frac{d\epsilon}{dt} + \frac{t^2}{2}\frac{d^2\epsilon}{dt^2} - \frac{t^3}{6}\frac{d^3\epsilon}{dt^3} + \frac{t^4}{24}\frac{d^4\epsilon}{dt^4} - \&c. \\
b' &= \frac{d\epsilon}{dt} - t\frac{d^2\epsilon}{dt^2} + \frac{t^2}{2}\frac{d^3\epsilon}{dt^3} - \frac{t^3}{6}\frac{d^4\epsilon}{dt^4} + \&c. \\
c' &= \frac{1}{2}\left(\frac{d^2\epsilon}{dt^2} - t\frac{d^3\epsilon}{dt^3} + \frac{t^2}{2}\frac{d^4\epsilon}{dt^4} - \&c.\right) \\
d' &= \frac{1}{6}\left(\frac{d^3\epsilon}{dt^3} - t\frac{d^4\epsilon}{dt^4} + \&c.\right) \\
e' &= \frac{1}{24}\left(\frac{d^4\epsilon}{dt^4} - \&c.\right)
\end{aligned}\right\}\text{IX.*}$$

equations by which, at any temperature, t, the values of a', b', c', d' and e' may be calculated in terms of ϵ and its derivatives, the relations between which have been already determined (I. to V.) The temperature specially adapted to this calculation is, however, the freezing temperature; for, putting $t = 0$ in equation IX. all but the first terms disappear.

It remains to be determined whether the successive terms in which ϵ is expressed,

$$\epsilon = a' + b't + c't^2 + d't^3 + e't^4 + \text{etc.}$$

form a convergent series.

Referring to equations I.—V. we see that the nth derivative of ϵ may be expressed

$$\frac{d^n\epsilon}{dT^n} = A\epsilon^{n+1} + B\epsilon^{n+2}\,T + \text{---} + X\epsilon^{2n+1}\,T^n,$$

* It will be noticed that equations IX. are the expression of the *converse* of Maclaurin's theorem, from which they might have been derived by considering ϵ as a constant, while a', b', etc. are variables. Not being able at once to find a proof of the proposition in this form, it was thought advisable to give the calculation in full. The theorem is known as Bernouilli's. See Williamson's Differential Calculus, § 64.

hence

$$\frac{d^{n+1}\epsilon}{dT^{n+1}} = A(n+1)\epsilon^n\left(\frac{7}{3}\epsilon^2 + \frac{4}{3}\epsilon^3 T\right)$$

$$+ B\left(\epsilon^{n+2} + (n+2)\epsilon^{n+1}\left(\frac{7}{3}\epsilon^2 T + \frac{4}{3}\epsilon^3 T^2\right)\right) + \cdots$$

$$+ X\left(n\epsilon^{2n+1}T^{n-1} + (2n+1)\epsilon^{2n}\left(\frac{7}{3}\epsilon^2 T^n + \frac{4}{3}\epsilon^3 T^{n+1}\right)\right).$$

The ratio of the term containing A in the $n+1^{st}$ derivative to the corresponding term in the n^{th} derivative is

$(n+1)\ \epsilon\left(\frac{7}{3} + \frac{4}{3}\epsilon T\right)$; that of the B term is

$\frac{1}{T} + (n+2)\ \epsilon\left(\frac{7}{3} + \frac{4}{3}\epsilon T\right)$; that of the last term is

$\frac{n}{T} + (2n+1)\ \epsilon\left(\frac{7}{3} + \frac{4}{3}\epsilon T\right)$; so that the successive derivatives ultimately form a divergent series.

Referring, however, to equation IX. we find

$$a' = \epsilon_0;\ b' = \frac{d\epsilon_0}{dt};\ c' = \frac{1}{2}\ \frac{d^2\epsilon_0}{dt^2} \text{ etc.}$$

$$(n+1)' = \frac{1}{n\,!}\ \frac{d^n\epsilon_0}{dt^n}$$

$$(n+2)' = \frac{1}{(n+1)\,!}\ \frac{d^{n+1}\epsilon_0}{dt^{n+1}}$$

so that the ratio of the $(n+2)^d$ to the $(n+1)^{st}$ term in the series,

$$\epsilon = a' + b't + c't^2 + d't^3 + e't^4 + \cdots + n't^{n-1}$$
$$+ (n+1)'t^n + (n+2)'t^{n+1} + \text{etc.},$$

will be

$$\frac{(n+2)'}{(n+1)'}\,t = \frac{t}{n+1}\ \frac{d^{n+1}\epsilon_0}{d^n\epsilon_0}$$

The last factor can be represented as the quotient of two sums, each of a number of terms; the ratio of no term in the numerator to the corresponding term in the denominator can by any possibility exceed

$$\frac{n}{T} + (2n+1)\,\epsilon\,(\frac{7}{3} + \frac{4}{3}\epsilon T),$$

so that the value of the quotient must be less than this quantity. Hence the ratio of the $(n+2)^{d}$ term to the $(n+1)^{st}$ in the expansion of ϵ cannot exceed the value

$$\frac{t}{n+1}\left(\frac{n}{T} + (2n+1)\,\epsilon\,(\frac{7}{3} + \frac{4}{3}\epsilon T)\right)$$

When n becomes indefinitely large, this ratio approaches the value $\frac{t}{T} + 2\epsilon t\left(\frac{7}{3} + \frac{4}{3}\epsilon T\right)$, so that if

$\frac{t}{T} + 2\epsilon t\left(\frac{7}{3} + \frac{4}{3}\epsilon T\right) < 1$, the series is certainly convergent.

Now t is necessarily less than T, since $T^{\circ} = 273^{\circ} + t^{\circ}$; and the smaller the value of ϵ, the greater can be the ratio of t to T without invalidating the convergence of the series.

If $t \overline{\gtrless} 0$, evidently ϵ_0 can be as great as one pleases, that is, the series is necessarily convergent for a descending scale of temperature.

If $t \overline{\gtrless} 60^{\circ}$ and $\epsilon < .002$

we have $2\epsilon t\left(\frac{7}{3} + \frac{4}{3}\epsilon T\right) < \frac{5}{6} < 1 - \frac{t}{T}$; hence the tables, which were constructed from $\epsilon = .0001$ to $\epsilon = .0020$, are at least reliable up to 60°.

In the same way ϵ is certainly determinate up to the value .00135 for at least 90°; and for still smaller values of ϵ_0, still higher temperatures may be used. It will be noticed that there is no liquid whose coefficient of expansion is as great as .002 which does not boil, at the ordinary pressure, below 60°; and none boiling above 90° has a greater coefficient than .00135, so that thus far theory and fact are not at variance. It must also be remembered that the ratio of a term to the one preceding it was shown

to be less than $\frac{t}{T} + 2\epsilon t\,(\frac{7}{3} + \frac{4}{3}\epsilon T)$ by assuming that the maximum ratio of the corresponding coefficients held for all. Since this is evidently not the case, the series is much more convergent than has been assumed, and there is every reason to believe that the value of ϵ is determinate for all temperatures below a certain critical point. Such a point is now believed to exist for all substances, above which the laws of liquid expansion will cease to apply. The correspondence of theory and fact in respect to this point will, if established, afford a complete physical demonstration of the sufficient convergence of our series.

The value of the critical temperature we are not yet prepared to calculate, owing to the difficulty of the mathematical solution; but in one of the sections following we shall see how it may be derived from our theory in a much more simple way.

It remains, therefore, to conclude that, since ϵ is determinate for all points below the critical temperature, the volume and its coefficients must also be determinate, and their calculation by means of the derivatives in Table I. is therefore perfectly legitimate.

Equations VII. enable us to determine the value of *a*, *b*, *c*, *d* and *e*, successively, for all values of ϵ at the temperature zero; and a table will be found at the end of the paper (II.) in which these coefficients are calculated for values of ϵ_0 from .0001 to .0020.

By means of these coefficients, a volume table has been constructed (III.) by which, when the value of ϵ_0 is known, the volume may be found, calculated at intervals of 10°, from —10° to 150° centigrade, the volume at zero being unity; and furthermore, by means of this table, if the volume be known at any temperature besides zero, the value of ϵ_0 and hence the volume at any other temperature may be deduced.

If, moreover, only the ratio of expansion be known for a given range of temperature, it will be possible to find by trial what value of ϵ_0 will account for this ratio, and thus to determine completely the laws of expansion of the substance.

The advantage of this method of treating expansion, which requires for substances not subject to a change of state only a single accurate observation in place of at least three, and which is the same for all bodies having the fundamental coefficient in common, is obvious; it remains only to see how closely our calculations are borne out by experience.

§ 8. The usual method of determining the law of expansion of a substance depends upon the assumption that the volume at any temperature, t, can be expressed sufficiently well by three constant coefficients, A, B, C, in the form

$$V = 1 + At + Bt^2 + Ct^3.$$

Four observations of the volume are usually made at different temperatures, the first being preferably zero, or, when that is impossible, the melting point. The other three, in absence of the data, may be assumed to have been chosen at equal intervals up to the boiling point, or the highest temperature observed. It is then always possible to assign such values to A, B and C as shall make the volumes calculated by the formula agree with those observed at all four temperatures. The values of the coefficients, A, B and C, as determined by Kopp and Pierre, have been tabulated by Sharples for about eighty-eight liquids, of which eleven were determined by both observers. In order to compare our results most directly with their figures, we must calculate the theoretical values of A, B and C which would represent the volumes correctly according

to Table III. at four different temperatures which may divide the whole range of temperature in question into three equal parts.

We have, for 0° and any three temperatures, t_1, t_2 and t_3, at which the formulae must hold, the simultaneous equations:

$$V_0 = 1,$$

$$V_1 \begin{cases} = 1 + At_1 + Bt_1^2 + Ct_1^3 & (1) \\ = 1 + at_1 + bt_1^2 + ct_1^3 + dt_1^4 + et_1^5 + \text{etc.} & (2) \end{cases}$$

$$V_2 \begin{cases} = 1 + At_2 + Bt_2^2 + Ct_2^3 & (3) \\ = 1 + at_2 + bt_2^2 + ct_2^3 + dt_2^4 + et_2^5 + \text{etc.} & (4) \end{cases}$$

$$V_3 \begin{cases} = 1 + At_3 + Bt_3^2 + Ct_3^3 & (5) \\ = 1 + at_3 + bt_3^2 + ct_3^3 + dt_3^4 + et_3^5 + \text{etc.} & (6) \end{cases}$$

Subtracting (2) from (1), (4) from (3), and (6) from (5), transposing in each case $(A - a)\ t$, and dividing by t, we have

$$A - a = -(B - b)\ t_1 - (C - c)\ t_1^2 + dt_1^3 + et_1^4 + \text{etc.} \qquad (7)$$

$$A - a = -(B - b)\ t_2 - (C - c)\ t_2^2 + dt_2^3 + et_2^4 + \text{etc.} \qquad (8)$$

$$A - a = -(B - b)\ t_3 - (C - c)\ t_2^3 + dt_3^3 + et_3^4 + \text{etc.} \qquad (9)$$

Subtracting (8) from (7) and (9) from (8) we have, transposing and dividing by $t_2 - t_1$ and $t_3 - t_2$, respectively,

$$(B - b) = -(C - c)\ (t_2 + t_1) + d\ (t_2^2 + t_2 t_1 + t_1^2) + e\ (t_2^3 + t_2^2 t_1 + t_2 t_1^2 + t_1^3) + \text{etc.} \qquad (10)$$

$$(B - b) = -(C - c)\ (t_3 + t_2) + d\ (t_3^2 + t_3 t_2 + t_2^2) + e\ (t_3^3 + t_3^2 t_2 + t_3 t_2^2 + t_2^3) + \text{etc.} \qquad (11)$$

Subtracting (11) from (10), transposing and dividing by $(t_3 - t_1)$, we have

$$C - c = d\ (t_3 + t_2 + t_1) + e\ (t_3^2 + t_2^2 + t_1^2 + t_3 t_2 + t_3 t_1 + t_2 t_1) + \text{etc.} \qquad (12)$$

Hence for any three temperatures, t_1, t_2 and t_3, at which the two formulae are assumed to agree, we can find the difference between C and c, and hence by substitution in (10) or (11) the value of $B - b$, which again, substituted in (7), (8) or (9), will give the excess of A over a.

If, however, the three temperatures, t_1, t_2 and t_3, are chosen at equal distances, as we presume in absence of contrary evidence that they are, we have $t_2 = 2t_1$ and $t_3 = 3t_1$;

$$\left.\begin{aligned} C &= c + 6dt + 25et^2 + \text{etc.} \\ B &= b - 11dt^2 - 60et^3 + \text{etc.} \\ A &= a + 6dt^3 + 36et^4 + \text{etc.} \end{aligned}\right\} \quad \text{I.}$$

where t is the lowest of the three temperatures at which the formula is exactly fulfilled.

Table IV. was constructed to show the different values of A, B and C corresponding to values of ϵ from .0001 to .0020, which must be chosen to represent correctly the volume at the extremes of three adjacent intervals of temperature, each equal to the figure at the head of the column, the lowest extreme being (strictly) zero. The table shows that the values of B and C may be very different according to the range of temperature chosen, and that A cannot be relied upon to represent the true coefficient of expansion at zero. As a practical confirmation of this indication of the theory, I will quote three different values of A for butyrate of ethyl, namely, .001202790, from 13° to 99°, and .000632742, from 99° to 119°.4, according to Pierre, while Kopp gives .001117817, probably for the whole range of temperature. It would seem, at first sight, impossible that two such careful observers could have differed by 50% in their estimation of the coefficient A from 99° to 119°, but if we compare the volumes indicated in each case, taking into account the other coefficients as well, we shall find differences which may easily be attributed to errors of observation.* The fact remains

* See Table VII.

that we cannot rely on these coefficients for the expansion at any temperature, however accurate the volumes may be. Before proceeding to a comparison of the results of our theory with those of observation, let us examine a little more closely into the probable error of the latter. The example quoted is an extreme case, and we will give Pierre the advantage of choosing the nearest of his two coefficients A, for comparison, thus considerably reducing the difference between the two observers; let us, moreover, take the mean of the coefficients in the case of fusel-oil and butyric acid, by which the agreement will be still further increased; we shall find nevertheless between Kopp and Pierre (by the method of squaring the errors), in the eleven liquids which they have determined in common, a mean difference for the coefficient A of .0000489 + (between four and five per cent.), for the coefficient B a mean difference of .000001318 + (nearly fifty per cent.) and for the coefficient C a mean difference of .00000001345 + (between sixty and seventy per cent. of the average value of the coefficient).

The details of the calculation are embodied in Table V., in which the figures of Kopp and Pierre are quoted in full from Sharples. It is thought that the figures will not need explanation.

§ 9. We are now prepared to make a direct comparison of theory and observation. Table VI. contains the values of A, B and C calculated and observed for 75 liquids, which may be identified by means of the numbers following their name and symbol in Table XVIII. It was not thought necessary to include in Table VI. the eleven liquids alluded to in the last section, as they are to be subjected to a much severer test. Besides these, the only two omitted from the table were sulphurous dioxide, which was out of the reach of the volume table, and is hardly a

liquid, and phosphorous chloride, which has a coefficient C some thousand times greater than the average (no other liquid exceeding it by more than seven times), thus clearly implying that this substance is an exception, like water, to the general law of expansion.*

We shall see that the existence of such exceptions does not militate, in any way, against the truth of our theory.

In the construction of Table VI. the calculated values of A, B and C were taken by interpolation from Table IV. so as to represent, as correctly as possible, both the volume and coefficient of expansion of the liquid, between 0° and the boiling point, using of course the table calculated for the given range of temperature.

The observed values are taken directly from Sharples' Tables, omitting however several figures which we have proved to be insignificant; when two values, not differing greatly, were given for different ranges of temperature, the mean was taken. The influence upon the result would in no case be perceptible.

The differences are given for the three coefficients A, B and C, calculated and observed; and it will be found that the mean difference for A being only .000,003,3, that for B is .000,001 +, and that for C, throwing out number 74, is .000,000,012 +, which we see in all cases is less than the mean difference between the two observers already found in the case of the eleven liquids which they determined in common.

It is proposed to subject these eleven liquids to a still more searching examination. At intervals of 10°, by aid of the empirical formula,

$$V = 1 + At + Bt^2 + Ct^3$$

* The probability of an error, by chance, exceeding the probable error, as in this case, by more than a hundred times was too small to be included in the tables of Chauvenet or in those of Haskell which are appended.

the volume, from 0° (or else the melting point) up to the boiling point in each liquid, has been calculated both according to Pierre and according to Kopp. These values will be found in Tables VII., in the columns headed V_P and V_K respectively.

The mean was then taken in the column $V_{P,K}$, and the difference between Kopp and Pierre, in the column headed Δ_{P-K}, is squared in the next column, Δ^2.

With the method of least squares, by actual trial, the best value of ϵ in Table III. was found, to represent the volume through the same range of temperature. The value of ϵ is given at the head of the table, and the volumes, taken from Table III. by interpolation, are in the column V_ϵ. The differences between these and the mean volumes, according to Kopp and Pierre, are given in the column $\Delta_{P,K-\epsilon}$, and the squares are given in the last column, Δ^2.

These columns of squares are added for each liquid, so that the sum of all the squares may easily be found.

Amongst this number, or amongst the seventy-five previously examined, if there be a single liquid (as for instance butyric acid) in which a molecular change affecting the volume is brought about by heat, the mean difference between theory and observation will be indefinitely increased; if there be the slightest *constant* error in the observation, the elimination of which is impossible, the observations will be equally accordant, but the theory will seem *unduly* to disagree; in all cases, the mean square of the difference between theory and observation will be increased by the sum of the mean squares of the errors from each source.

There is no reason to suppose that the constants of the standards, in terms of which the expansion was expressed, as, for instance, the coefficients of expansion of mercury and glass, determined by Regnault, were more accurately

measured than any of the rest, being equally subject to thermometric error; if this be true, then, according to the theory of probability, the mean error of the results of Kopp and Pierre combined will be, not one-quarter of their mean difference, as would be the case if the standards were absolutely reliable, but one-half or three-quarters, according as we assign to Regnault (or whatever standard they may have used) the weight of two observers or that of only one.

Where, as in the present case, the mean difference of theory and observation is equal to about two-thirds of the mean difference of two observers, the discrepancy is probably due to errors of observation. It would appear that for ten out of the eleven liquids most closely examined,—the exception being butyric acid—the agreement is actually greater than probability could require even if the theory (as well as the standards) were known to be absolutely true.

In the case of solids, according to the results obtained by Dr. Matthiessen, the law of expansion will need to be modified. I have already pointed out that if the molecule or atom were itself compressible, the indication of the kinetic theory would not be strictly fulfilled; the departure can easily be subjected to mathematical computation, and its value determined, constantly increasing with the state of aggregation.

It appears to me, however, that the facts do not justify such a laborious calculation. It is to be observed that in weighing in water, as in the experiments of Dr. Matthiessen, any error in the determination of the density of the water,* or of its temperature, will affect the results by a proportionate amount.

* The mean difference between Kopp and Pierre for water [see Table, Sharples, page 73] is a little more than .0005, or one-twentieth of one per cent., corresponding to an error of one-tenth of one degree in temperature.

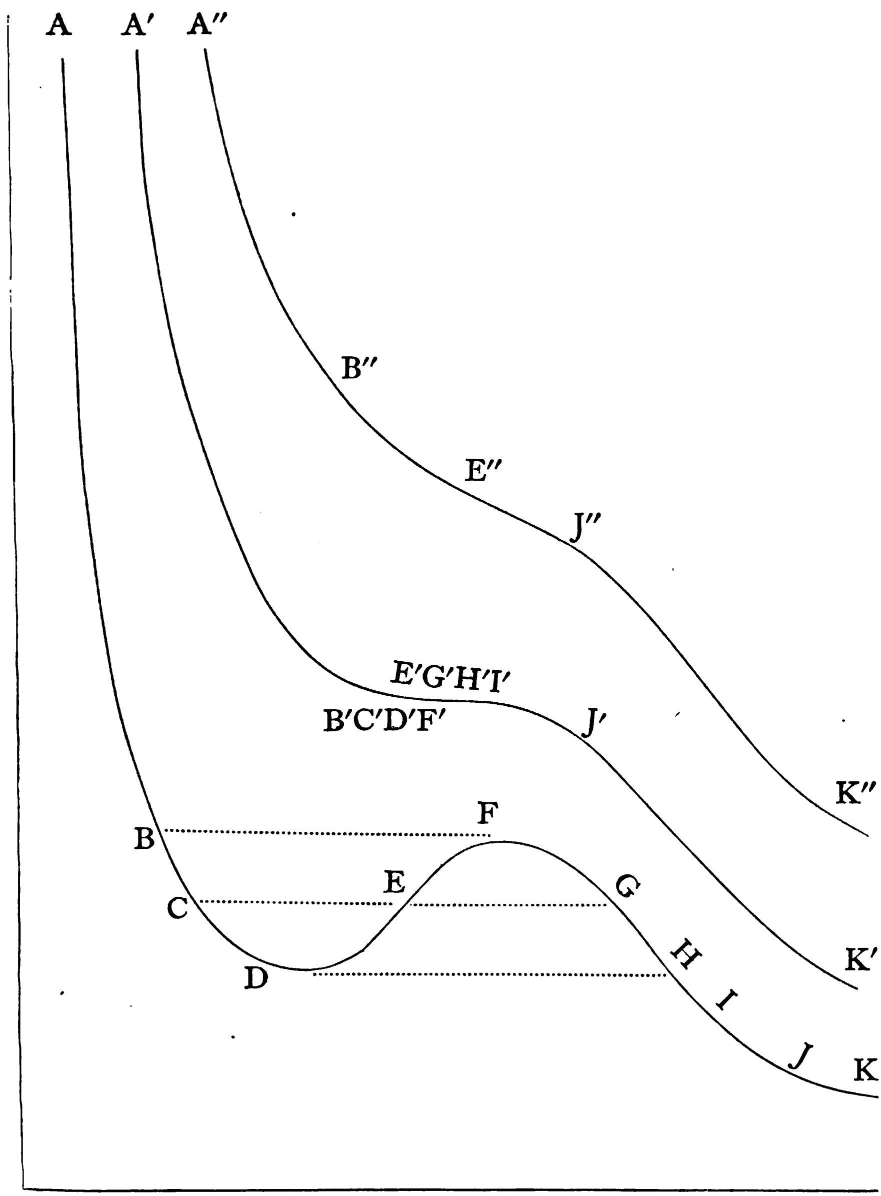
In conclusion, concerning *all* the results which have been brought forward (which are the best that I have been able to find) I would suggest that until we discover some more accurate method of measuring temperature than we at present possess, it will be useless to hope to obtain in any thermometric measurement of the rates of change of expansion more than an approximation to the truth.

It is therefore absurd to base a theory even upon such precise measurements as those of Dr. Matthiessen. The atoms are undoubtedly compressible, but we shall be unable to obtain a measure of their compressibility in this way, and we have no reason thus far to suppose that the theory of expansion, developed for the lighter liquids, is not applicable, without modification, to solids.

The result of the investigation suggests that the treatment of matter in its different states may differ only in that here, one factor, there, another, can in practice be neglected; and that the Laws of Expansion are fundamentally the same for all bodies, whether they be solid or liquid, vapor or gas.

§ 10. Maxwell has pointed out in his *Theory of Heat*, chapter V., page 107, that the elasticity of a fluid is expressed by the quotient of the *slope* of a curve by the *volume*, which is its abscissa, while the ordinate is the pressure. Hence if the volume be unity, the slope and elasticity are equal. The present section is devoted to the analytical investigation of elasticity and its application to isothermal curves.

"It has been suggested by Professor James Thomson" (see Maxwell, chapter VI., page 124), "that the isothermal curves" [of liquids in contact with their vapors] "for temperatures below the critical temperature are only apparently, and not really, discontinuous, and that their true form is somewhat similar in its general features to the curve *ABCDEFGHK*."


A
A′
A″
B″
E″
J″
E′G′H′I′
B′C′D′F′
J′
K″
F
B
E
G
C
H
D
I
J
K′
K

"The peculiarity of this curve is that between the pressures indicated by the horizontal lines, BF and DH, any horizontal line, such as CEG, cuts the curve in three different points. One of these, indicated by C, evidently corresponds to the liquid state. Another, indicated by G, corresponds to the gaseous state."

Maxwell continues to the effect that E may be left out of consideration, being a point of unstable equilibrium.

Curves are also given of the general form $A'B'C'D'E'F'G'H'K'$ and $A''B''E''J''K''$, representing isothermals at and above the critical temperature. All these curves are concave upward as far as a certain point, such as E, then convex as far as J, and finally concave again. The slope of all is at first downwards, and finally downwards. Below a certain isothermal, the concave curvature is sufficient to cause an upward slope between D and F; above it, it is insufficient; and this particular isothermal is characterized by having a slope which reaches zero as its limit and then tends downward again. Now unless the curvature changed its sign at the point where the curve becomes horizontal, the slope on one or the other side of this curve would be upward; hence we may determine this curve by supposing the slope and curvature to be equal simultaneously to zero. It is evident, moreover, that this is a complete definition of the curve, since no other can at any point fulfil the same conditions.

It is hardly necessary to add that this isothermal belongs to what is called the "critical temperature." Below it, since at E the slope is upward, there can always be found for a given pressure two volumes, C and G, at which the substance is in stable equilibrium. Above it, since the slope is always downwards, only one state is possible. That is, the temperature of this isothermal is the limit up to which a liquid is possible in contact with its vapor.

The method of treating isothermals and determining the critical temperature by the theory is extremely sim-

ple. We have merely to put the elasticity which we have found in § 6, II.,

$$E = \frac{P'}{3}\left(\frac{4l' - 3l}{l - l'}\right) - 2\,\overline{P},$$

and its derivative with respect to the volume, or l, which amounts to the same thing, simultaneously equal to zero. We shall first find an expression for the ratio of l' to l, *in the critical state itself*, which will enable us to calculate successively the cohesive, the internal, the external pressures, the density and the critical temperature, which latter, being found for one point of the curve, is the same of course for all. These are all the constants which we need to determine.*

The formula for the elasticity may also be written, since $\overline{P} + P' + \overline{P}'' = 0$,

$E = \frac{P'}{3}\left(\frac{3l - 2l'}{l - l'}\right) + 2\overline{P}''$, whence, substituting the values of P' and P'' in terms of P'_0 and P''_0,

$$E = \frac{P'_0}{3}\,\frac{l_0^2}{l^2}\,\frac{(l_0 - l')}{(l - l')}\,\frac{T}{T_0}\,\frac{(3l - 2l')}{(l - l')} + 2\,P''_0\,\frac{l_0^6}{l^6}$$

$$= \frac{P'_0}{3}\left(\frac{l_0^2}{l^2}\,\frac{l_0 - l'}{l - l'}\,\frac{T}{T_0}\,\frac{3l - 2l'}{l - l'} - 6\,\frac{l_0^6}{l^6}\left[1 + \frac{\overline{P}_0}{P'_0}\right]\right) \quad \text{I.}$$

Differentiating with respect to l, and remembering that all other factors are constant, we have

$$\frac{dE}{dl} = \frac{P'_0}{3}\left\{\begin{array}{l} \dfrac{3l^2\,(l - l')^2\,l_0^2\,(l_0 - l')\,T}{l^4\,(l - l')^4\,T_0} \\[2ex] -\dfrac{2(l^2(l - l') + l\,(l - l')^2)\,l_0^2(l_0 - l')\,(3l - 2l')\,T}{l^4\,(l - l')^4\,T_0} \\[2ex] +\,36\,\dfrac{l_0^6}{l^7}\left[1 + \dfrac{\overline{P}_0}{P'_0}\right] \end{array}\right\}$$

---

* The elasticity being zero, the coefficient of expansion will be indefinitely great at that point; the latent heat will disappear, and instead we shall find an enormous specific heat under a sufficiently great constant pressure, falling off rapidly as the temperature is increased. The surface tension is very closely related to the cohesive pressure, and the distinction between vapor tension and external pressure disappears.

$$\frac{dE}{d\log l} = \frac{P'_0}{3}\left(36\frac{l_0^6}{l^6}\left[1+\frac{\overline{P}_0}{P'_0}\right]-\frac{l_0^2(l_0-l')\,T}{l^2(l-l')\,T_0}\frac{[(3l-2l')^2+ll']}{(l-l')^2}\right) \quad \text{II}$$

The left hand term in the parenthesis is essentially positive; the right hand term essentially negative, since $l > l' > 0$ and $l_0 > l'$. When l becomes very great, the left hand term disappears in comparison with the other; as $l - l'$ approaches zero the right hand term becomes infinite, so that at both extremes the curvature is concave upwards. Between the two, it is evident that, if $\frac{T}{T_0}$ is sufficiently small, the right hand term will become less than the left hand, and the curvature will become convex upward. There will therefore in general be two middle points where the curve is perfectly straight.

From I. we see that when $l = l'$, $E = \infty$, that is, the curve becomes parallel to the axis of pressures with an infinite downward slope; when l increases indefinitely, the curve approaches the axis of volumes as an asymptote, and the slope becomes positive before it vanishes owing to the disappearance of the second term in parenthesis in comparison with the first. Between these values, if $\frac{T}{T_0}$ is sufficiently small, the slope evidently becomes negative somewhere, and in changing to negative and then to positive again, must twice pass through the value zero. Hence there will be in general two points, D and F, where the curve is parallel to the axis of volumes. When, however, T is increased, it is at last impossible for the slope to become negative; there must be some value for T when the slope reaches the value zero without crossing it; for we may put E and its derivative simultaneously equal to zero, and the isothermal in question fulfils all the conditions which should hold at the critical temperature.

It is easy to show that all the curves in the neighborhood of the critical temperature have the general charac-

teristics which were anticipated by Professor Thomson; and to prove by a second differentiation, as well as by actually plotting these curves, that the elasticity and its derivative do not more than twice pass through the value zero. We have, therefore, every reason to expect that the true form of the equation may have been found for the curves whose characteristics were predicted thirteen years ago.

If we suppose equations I. and II. to be simultaneously equal to zero, we have, multiplying I. by 6, dividing both equations by $\frac{P'_0}{3}$, and transposing,

$$\frac{6l_0^2(l_0-l')}{l^2(l-l')}\frac{T}{T_0}\frac{(3l-2l')}{(l-l')}=\frac{36l_0^6}{l^6}\left[1+\frac{\overline{P}_0}{P'_0}\right]$$

$$\frac{l_0^2}{l^2}\frac{(l_0-l')}{(l-l')}\frac{T}{T_0}\frac{(3l-2l')^2+ll'}{(l-l')^2}=\frac{36l_0^6}{l^6}\left[1+\frac{\overline{P}_0}{P'_0}\right]$$

whence

$$\frac{6l_0^2}{l^2}\frac{(l_0-l')}{(l-l')}\frac{T}{T_0}\frac{(3l-2l')}{(l-l')}=\frac{l_0^2}{l^2}\frac{(l_0-l')}{(l-l')}\frac{T}{T_0}\frac{(3l-2l')^2+ll'}{(l-l')^2}$$

Clearing of fractions and common factors,

$$6\,(l-l')\,(3l-2l')=(3l-2l')^2+ll'$$

$$18l^2-12ll'-18ll'+12l'^2=9l^2-12ll'+4l'^2+ll'$$

$$9l^2-19ll'+8l'^2=0$$

$$l^2-\frac{19}{9}ll'+\left(\frac{19}{18}\right)^2l'^2=\left(\frac{19}{18}\right)^2l'^2-\frac{8}{9}l'^2$$

$$\frac{l}{l'}=\frac{19}{18}\pm\sqrt{\left(\frac{19}{18}\right)^2-\frac{8}{9}}$$

Since l is essentially greater than l', only the positive root is to be taken, and we have, finally, in the critical state, the condition,

$$\frac{l}{l'}=1.53022 \qquad \text{III.}$$

Substituting this value in the equation

$$E=\frac{P'}{3}\left(\frac{3l-2l'}{l-l'}\right)+2\bar{P}''=0, \text{ we have}$$

$$\frac{P'}{P''}=1.228, \text{ nearly, whence}$$

$$\frac{P}{P''}=0.228, \text{ nearly.}$$

Substituting for P'' its value, $P_0''\frac{l_0^6}{l^6}=P_0''\left(\frac{l_0}{l'}\right)^6\left(\frac{l'}{l}\right)^6$

$$P'=0.09566\left(\frac{l_0}{l'}\right)^6 P_0'' \qquad \text{IV.}$$

$$P=0.01776\left(\frac{l_0}{l'}\right)^6 P_0'' \qquad \text{V.}$$

The last expression was obtained by taking the difference of two very nearly equal values, and is therefore not very reliable. If the atoms are spherical, the apparent molecular diameter (or shortening of the free path) will be less, the further the molecules are apart; in a linear expansion, therefore, of from forty to fifty per cent., we must on this account look for a greater free path, and consequently a less kinetic pressure; furthermore, since for great distances the law of variation of the magnetic attraction is inversely as some power much greater than the fourth, and we have supposed that the average power is the fourth, it follows that at short distances the attraction, according to the analogy, cannot vary quite so rapidly. Both these causes combined would tend to diminish the external pressure, the first by lessening the frequency of impact of the molecules (or atoms), the second by holding them more closely together; the result is that we must expect to find that the external pressure, calculated in this way, is considerably too great.

By inspection of the figures given, it will be seen that a combined variation of about twenty per cent. in these two pressures would annihilate completely the external pressure; hence if the observed values lie between zero and those calculated, the total error due to disturbing causes cannot exceed twenty per cent.

For the critical temperature, T_1, we have from §2, I. (see § 6, init.) the formula,

$$P' = P_0' \left(\frac{l_0^2}{l^2} \frac{(l_0 - l')}{(l - l')} \frac{T}{T_0} \right)$$

$$\text{Hence } \frac{T_1}{T_0} = \frac{P_1'}{P_0'} \frac{l_1^2 (l_1 - l')}{l_0^2 (l_0 - l')}$$

$$= 0.09566 \left[\frac{l_0}{l'} \right]^3 \frac{P_0''}{P_0'} (1.5302)^2 (.5302) \frac{l_0}{l_0 - l'}$$

or, finally,

$$\frac{T_1}{T_0} = .11876 \left(\frac{l_0}{l'} \right)^3 \frac{P_0''}{P_0'} \frac{l_0}{l_0 - l'} \qquad \text{VI.}$$

an equation by which the value of the critical temperature may be determined when we know at any temperature T_0 the ratio of l' to l_0. We have seen reason to expect that our formulae are to be relied upon within ten or twenty per cent. and shall hope to find, accordingly, later on, that the values of the critical temperature, calculated by this formula, are sufficiently close to those estimated by Cagniard de la Tour.

§ 11. The surface tension of a liquid is very easily determined by means of the height to which it will rise in a capillary tube, of known diameter, which it thoroughly wets. It is believed that the surface tends to contract with a perfectly measurable force, not depending upon the depth of the liquid, but being the same for the thin-

nest possible film (in a soap-bubble for instance), as in the surface of deep water. The contractile force depends, accordingly, upon the breadth of the film, and not on its thickness; and in Everett's *Units and Physical Constants* (page 42, § 46) we find the tension in dynes of a surface a centimetre broad. Since a film has two surfaces, each with a tension independent, nearly, of the thickness as assigned, to produce a given film would require a perfectly measurable quantity of work, which, in the thinnest possible films, must be a considerable fraction of that necessary to convert the liquid into vapor.

This fraction is easily determined theoretically. For the latent heat, instead of the series,

$$12\left(1 + (\tfrac{1}{2})^2 + (\tfrac{1}{3})^2 + (\tfrac{1}{4})^2 + \text{etc.}\right)$$

which represents the equivalent of the total number of atoms from which a given atom has to be separated, we now have only

$$6\left(1 + (\tfrac{1}{2})^3 + (\tfrac{1}{3})^3 + (\tfrac{1}{4})^3 + \text{etc.}\right)$$

the molecules all lying in one plane. From each of these must be subtracted, as before, the equivalent of the number of atoms which remain clinging to a given atom in the state of vapor. The value of the last series, which is the more convergent of the two, is easily found to be 7.206, which, subtracted from the first series, or 19.740, leaves 12.534 to represent the work done in stretching the film.

Hence the fraction of the work spent in this way is $\frac{12.534}{K\,(19.740)}$, or for ordinary liquids about two-thirds of that required for complete vaporization.

It is therefore easy, if we know the principal ratio, K, to find the thickness of the thinnest possible film. To generate each square centimetre of such a film, the tension

(S) of each surface must be overcome through the distance of one centimetre, requiring an expenditure of energy equal numerically to twice this tension; the density of the film being D and the thickness l, the weight will be lD and the equivalent of the internal latent heat $JLlD$, about two-thirds of which is required to *laminate* the liquid in this way. Equating the two expressions for the work, we have $\frac{12.534\,JLlD}{(19.740)\,K} = 2\,S$, whence

$$l = \frac{3.15\,KS}{JLD}, \qquad \text{II.}$$

a formula by which the absolute thickness of a molecular film may be calculated according to the theory.*

If we could regard the cohesive pressure across a square centimetre of surface as the sum of the contractile forces of a sufficient number of films of thickness l, and cutting the surface at right-angles, we should at once obtain an expression for the cohesive pressure; but we must remember to take into account the effect of oblique action, and the accumulative attraction of successive shells, which will increase the results in the ratio of the two series, (1) and (2),

$$(1) \qquad \begin{array}{r} 1 + (\tfrac{1}{2})^3 + (\tfrac{1}{3})^3 + (\tfrac{1}{4})^3 + \text{etc.} \\ + (\tfrac{1}{2})^3 + (\tfrac{1}{3})^3 + (\tfrac{1}{4})^3 + \text{etc.} \\ + (\tfrac{1}{3})^3 + (\tfrac{1}{4})^3 + \text{etc.} \\ + (\tfrac{1}{4})^3 + \text{etc.} \\ + \text{etc.} \end{array}$$

$$(2) \qquad \begin{array}{r} 1 + (\tfrac{1}{2})^4 + (\tfrac{1}{3})^4 + (\tfrac{1}{4})^4 + \text{etc.} \\ + (\tfrac{1}{2})^4 + (\tfrac{1}{3})^4 + (\tfrac{1}{4})^4 + \text{etc.} \\ + (\tfrac{1}{3})^4 + (\tfrac{1}{4})^4 + \text{etc.} \\ + (\tfrac{1}{4})^4 + \text{etc.} \\ + \text{etc.} \end{array}$$

* The usual expression for this thickness, $l = \frac{2\,S}{JLD}$, entirely disregards the fact that the liquid is only partly volatilized when reduced to a thin film. For the results of another method of calculating the molecular diameter, see Rühlmann, Volume II., page 237.

The first series is evidently equal to

$$1 + (\tfrac{1}{2})^2 + (\tfrac{1}{3})^2 + (\tfrac{1}{4})^2 + \text{etc.} = \frac{\pi^2}{6}$$

the second is equal to

$$1 + (\tfrac{1}{2})^3 + (\tfrac{1}{3})^3 + (\tfrac{1}{4})^3 + \text{etc.}$$

which is equal to 1.201 + ; so that we have

$$P'' = \frac{3.15\ S}{l} \qquad \text{III.}$$

which, combined with II., gives by an independent method of reasoning the same result as before, namely,

$$JLD = K\,P'',$$

since we have disregarded signs, and have considered the external pressure equal to zero.

Now the thickness of a molecular film, having been determined by various methods for a few elementary substances, can be calculated for any substance whose graphical symbol is known;* and hence if the surface tension is given, formula III. enables us to determine the cohesive pressure, and indirectly any of the other physical constants in terms of which it may be expressed.

§ 12. The difference between the specific heats of a substance in the liquid and in the gaseous state is, as we have seen, *other things being equal*, the measure of the work done in separating the particles by the amount corresponding to an increase of one degree in temperature. The sum of all such elementary quantities of work done in an indefinite expansion is the internal latent heat of vaporization; and, conversely, we may regard the difference of these two specific heats as the change of the internal latent heat per degree of temperature, or, what is the same thing, the derivative of this latent heat with respect to the temperature.

In order, however, that this rule may apply in all strictness, the temperature of the liquid and vapor whose specific

* See also Rühlmann, ibid. "Untersuchungen über die absoluten Grössen der Molecüle."

heats are compared must be the same; and of course the specific heats must be corrected for the external work done in each case. For liquids this may generally be disregarded; but for vapors we must multiply the external pressure in dynes by the coefficient of expansion, remembering to divide by 42,000,000 and by the density, if the result is to be expressed in heat units per unit weight. Deducting this number from the ordinary specific heat, we have that under constant volume. The specific heat of the liquid at the same temperature necessarily exceeds this by the amount of the diminution of the latent heat of vaporization per unit of temperature.

To find an expression for this difference, we have merely to differentiate the equation for the latent heat already found, namely,

$$JLD = \frac{K}{3} D v_0^2 \frac{m_1}{m} \frac{T}{T_0} \frac{l}{l-l'},$$

where we notice that D may be cancelled, and that K is the principal ratio, not far from unity, which we have already calculated for several liquids.

In the liquid or solid state, it must be supposed that the expansion is accompanied by a grouping of the atoms; hence K must not be disregarded, and we have

$$J\frac{dL}{dT} = \frac{K}{3}\frac{v_0^2}{T_0}\frac{m_1}{m}\left(\frac{((l-l')-l)}{(l-l')^2}T\frac{dl}{dT} + \frac{l}{l-l'}\right)$$

$$= \frac{K}{3}\frac{v_0^2}{T_0}\frac{m_1}{m}\frac{l}{(l-l')} - \frac{K}{3}\frac{v_0^2 m_1 T}{m T_0}\frac{l'}{(l-l')^2}\frac{dl}{dT}.$$

$= J(H'-H)$, where H and H' are the specific heats of the liquid and of the vapor.

Substituting for $\frac{dl}{dT}$ its value $\frac{\epsilon l}{3}$, we have

$$J(H-H') = \frac{K}{9} v_0^2 \frac{m_1}{m}\frac{T\epsilon}{T_0}\frac{l'l}{(l-l')^2} - \frac{K}{3}\frac{v_0^2}{T_0}\frac{m_1}{m}\frac{l}{(l-l')} \quad \text{I.}$$

a formula by which we may determine the difference of specific heats if we know the coefficient of expansion, the factor K and the ratio of l' to l.

The formula may also be written, substituting L for its value,

$$(H - H') = L\left(\frac{\epsilon l'}{3\,(l - l')} - \frac{1}{T}\right), \qquad \text{I. } a.$$

still involving the ratio of the molecular diameter to the free path.

But since the work done in expansion is the product of the coefficient by the pressure overcome, less the affinity satisfied, we may also write

$$J\,(H - H') = KP''\epsilon, \qquad \text{II.}$$

in which, substituting any value of P'', we have from III. § 11, from II. § 1, and from III. § 1,

$$J\,(H - H')\;D = K\,\frac{3.15\;S\epsilon}{l} = JLD\epsilon = KE\epsilon^2 T, \qquad \text{III.}$$

whence we see that $(H - H') = L\epsilon$. IV.

By means of these formulae the difference may be determined between the specific heat in the liquid state and that under constant volume in the state of vapor.

§ 13. We have now considered the principal physical constants, and we find, with the exception of a few relations between them which are independent, that all involve in some way the ratio of the molecular diameter to the free path. It does not, therefore, seem surprising that the relations which still remain to be established should have escaped the notice of a scientific world which has until recently* been bent upon the solution of the molecular theory of liquids and solids on the false supposition that the molecules were very far apart, and the repulsive

* See Rühlmann, ibid.

forces exerted at considerable distances, the atoms being hypothetically soft though perfectly elastic bodies.

In the next section we shall consider the ratio of the molecular diameter, or shortening of the free path, to the whole molecular distance; the object of the present section is to obtain formulae for actual use, from which this troublesome factor may have been eliminated.

We have already obtained three equations independent of the free path, namely,

$$\frac{JLD}{E\epsilon T} = K, \tag{1}$$

$$\frac{JLDl}{3.15\,S} = K, \tag{2}$$

$$L\epsilon = H - H'. \tag{3}$$

We have, moreover, equations involving the ratio of l' to l, namely,

$$E\epsilon = \frac{D}{3} \cdot \frac{v_0^2}{T_0} \, \frac{m_1}{m} \, \frac{l}{l - l'}, \tag{4}$$

$$\epsilon = \frac{3}{T} \, \frac{l - l'}{4l' - 3l}, \tag{5}$$

and

$$\left(\frac{l'}{l}\right)^3 \left(1 - \frac{l'}{l}\right) = .11876 \frac{T}{T_1} \, \frac{(P' + \overline{P})}{P'}. \tag{6}$$

In these equations J, T_0, v_0^2 and $\frac{m_1}{m}$ are well-known physical constants.

$J = 42{,}000{,}000$ (C. G. S.)

$v_0^2 = 33{,}948{,}000{,}000$ (C. G. S.)

$T_0 = 273°$ (Centigrade).

$\frac{m}{m_1}$ is half the "molecular weight."

K is the "principal ratio" defined above, which may be calculated approximately for a homogeneous substance by the formula,

$$K = 1 - \frac{\Sigma m \mathfrak{Q}}{20 \Sigma m},$$

$\mathfrak{Q}$ being the "*quantivalence*" of the atom whose molecular weight is m.

Finally the thickness of the molecular film, l, which is closely connected with the absolute weight of the molecule, may be calculated with more or less accuracy by reasoning from its value in a known case to that in an unknown. For this, of course, an approximate knowledge of the atomic grouping is necessary.

It is evident that two more data must be had in order to obtain a complete solution of the problem, and these are evidently the free path and the strength of the attraction of each atom. That is, we must have a description in full of the nature and distribution of the material with which we have to deal, in order to be able to predict its specific properties under any imposed conditions.

The determination of the density is evidently equivalent to that of the free path, for, under given conditions of pressure, volume and temperature, the free path is determined, by the kinetic theory, when the density and molecular weight are given; but we are yet unable to determine the attractive power of the various elementary atoms, owing to the insufficiency of the data. It is evident, therefore, à priori, that the absolute calculation of the physical constants will be impossible, until by sure but laborious methods these atomic constants shall have been worked out.

We have, therefore, to depend upon six equations to determine the ratios between seven unknown quantities, which is clearly possible. These seven quantities are

the free path, latent heat, elasticity, expansion, critical temperature, specific heat, and capillarity; and it is evident that we may completely eliminate the free path, and have five equations connecting the remaining constants, or, if we choose to leave out the surface tension, which alone involves the doubtful factor l, have left four equations connecting the five most important physical constants. It follows that, if the value of a single one of these is given, that of all the rest will be determined; if two are given, then the others may be determined, independent either of the molecular distance or of the principal ratio; if three are given, all may be determined, independent of any theoretical consideration.

It is not proposed to work out a multitude of equations which can evidently arise from the various combinations of these quantities; it will be sufficient to deduce a few which will be found convenient for actual use, and others by which the Theory may be thoroughly tested.

For instance, from (1), (4) and (5),

$$Lm\epsilon = (5.922 + 7.896\epsilon T)\left[1 - \frac{\Sigma m\mathcal{Q}}{20\Sigma m}\right] \qquad \text{I.}$$

From (1) we have

$$LJD = E\epsilon T\left[1 - \frac{\Sigma m\mathcal{Q}}{20\Sigma m}\right] \qquad \text{II.}$$

From II. and (2) we have

$$lLJD = 3.15\ S\left[1 - \frac{\Sigma m\mathcal{Q}}{20\Sigma m}\right] \qquad \text{III.}$$

From II. and III. we have

$$lE\epsilon T = 3.15\ S. \qquad \text{IV.}$$

From III. and (3),

$$l\,(H - H')\,JD = 3.15\ S\epsilon\left[1 - \frac{\Sigma m\mathcal{Q}}{20\Sigma m}\right] \qquad \text{V.}$$

From (3) directly,

$$(H - H') = L\epsilon. \qquad \text{VI.}$$

From I. and VI.,

$$(H - H')\, m = (5.922 + 7.896\epsilon\; T) \left[1 - \frac{\Sigma m \mathfrak{Q}}{20 \Sigma m}\right] \qquad \text{VII.}$$

From IV. and V.,

$$(H - H')\, JD = E\epsilon^2 T \left[1 - \frac{\Sigma m \mathfrak{Q}}{20 \Sigma m}\right] \qquad \text{VIII.}$$

From (4) and (5),

$$E\, \epsilon^2 m\, T = 82{,}898{,}000\; (3 + 4\epsilon T)\dot{D}. \qquad \text{IX.}$$

And finally, from (5) and (6),

$$T_1 \epsilon\, (3 + 3\epsilon T)^3\, P' = 0.11876\; (3 + 4\epsilon T)^4\; (P' + \overline{P}). \;\text{X.}$$

These formulae nearly all involve ϵ, which is one of the most generally, if not most accurately, known of all the physical constants, thanks to the efforts of Kopp and Pierre. When, however, as in the case of water, the coefficient is hidden under some molecular change, the value may easily be eliminated. It should be remembered, however, that any molecular change that affects the expansion will also alter the compressibility, so that we can no longer depend upon the value of E.

The relations between the other constants will not in general be disturbed.

§ 14. The truth of the ten equations of the last section is easily shown, in the case of most liquids, to hold within reasonable limits. In many cases, if not in most cases, the error committed by using these formulae is not large as compared with the error of actual observation. To examine in detail the application of these equations to the hundred or more substances whose constants have been determined would require an almost endless amount of labor. A brief consideration may not be out of place.

The general truth of the first equation was anticipated in Miller's *Chemical Physics*, where, on page 342, he gives a table of the *Latent heat for equal Volumes.* The cause of the variation of these latent heats, together with that of their approximate agreement, is now explained, being due to the fact that the coefficient of expansion varies through narrow limits for all ordinary liquids.

The average value of the product of the *internal* latent heat by the molecular weight is easily found from Miller's Table to be about 7,700. The average value of the coefficient of voluminal expansion at the boiling point (say 80°) is not far from .0012;* the product is therefore about 9.2, and the second term is equal to $5.9 + 3.3$, or 9.2 about, which sufficiently establishes the general truth of the formula.

The second formula has been already discussed; the third and the two following are of interest as giving the absolute thickness of a molecule.

We have for water in equation III.

$$l = \frac{3.15 \times 81 \times .93}{575 \times 42{,}000{,}000 \times 1}$$ = about ten thousand-millionths of a centimetre, instead of forty-six, according to Rühlmann. Professor Cooke has suggested five thousand-millionths as the most probable number.†

The formulae for the difference of the internal specific heats of the liquid and vapor are easily shown to agree, as nearly as could be expected, with the observations of Regnault, in which these two specific heats are in no case determined for the same range of temperature.

The specific heat of ether vapor is, for instance, 0.48, nearly, from which, deducting 0.03 for external work, we

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* See Tables for expansion, Sharples, pages 68-72.

† In the *New Chemistry*, page 34, fin.

have 0.45 for the specific heat under constant volume, for a range of temperature from 70° to 220°. Now since the specific heat of ether is 0.53 at 0° and 0.55 at 35°, we may assume that at 70° it would be about 0.57, and at 140° about 0.61, the excess being in the neighborhood of 0.14; the latent heat being 82 (Regnault — Zeuner) and the relative coefficient of expansion about .0017, we should have for both sides of equation VI. the number 0.14, so that, as far as these figures show, the relation may be perfectly exact.

The case of bromine is of unusual interest, it being an elementary liquid; in equation VII. we have without any correction $H - H' = .0574$, which multiplied by the molecular weight (160) gives 9.2, nearly. The coefficient of relative expansion being about .0013 at the given temperature (80° +), gives about 3.7 for the second term in the parenthesis; adding we have 9.6, which finally multiplied by the principal ratio (.95) gives 9.2, nearly, for the other side.

There are many other cases of agreement, and indeed it may be said that there is no case in which the truth of the formulae for specific heat can be disproved; nevertheless, the evidence is negative, and all that is claimed for these formulae is to represent approximately the difference between the specific heats of the liquid and vapor.

When it comes to solid bodies, or such a dense liquid as mercury, a glance will be sufficient to show that these formulae for specific heat do not hold at all; and neither does formula IX. connecting the elasticity and expansion. It would appear as if the cohesive force varied inversely as some power of the distance much less than the fourth, as would be the case if the molecules were in absolute contact during even a considerable portion of the time which we suppose to be occupied by a vibration. By referring to the original formulae, it will be seen that the rate of expansion will be greatly diminished in this case; and hence the constants will nearly all be affected.

The laws for dense solids could easily be established by the same methods of reasoning; but their discussion would exceed the intended limit of this paper. It may, however, be observed that the products of the coefficients are usually from one-third to one-half as great for solids as for liquids, and that the law of variation of the force which binds them together, being compounded probably of attractive and repulsive forces, appears to vary inversely as some power of the distance not far from the square.

The critical temperatures calculated by formula X. come out, for the four liquids examined by Cagniard de la Tour, about ten per cent. higher than his estimate; it is possible that under different conditions a more elevated temperature might have been required, but it is more likely that the theory is at fault. Many considerations have been left out of account which would indicate just such an error. In particular I would mention the same causes which led us before to expect a still greater divergence in the expressions for the pressure at this temperature (§ 10) and the difference between the mean and probable velocity of the molecule, all of which considerations must at present be passed over.

The ten equations of the last article appear to be borne out by experience in the case of a hundred liquids, as closely as one would have a right to expect, in view of the minor considerations which have been of necessity disregarded. By means of a more general analysis, outlined in § 16, I have been able to prove that the same would not have been true if we had assigned an essentially different law to the variation of the cohesive force; the relations calculated between all these constants would have been in that case entirely out of proportion.

§ 15. To facilitate the use and application of the formulae of § 13, connecting the latent heat, elasticity, expan-

sion, specific heat, critical temperature and surface tension, tables have been constructed expressing the value of each of these constants in terms of the ratio of l' to l_0, called the *Principal Argument*. In the case of the coefficient of expansion, the ratio was calculated in Table X. explicitly in terms of ϵ, for 0° centigrade, by means of the formula I. *a*, of § 7,

which became $$\frac{l'}{l_0} = \frac{3 + 819\,\epsilon_0}{3 + 1092\,\epsilon_0} \qquad \text{I.}$$

For the critical temperature (T_1) in Table XI. formula (6) of § 13 was employed, at the temperature zero, neglecting the external pressure. This became

$$T_1 = 32.42 \div \left(\frac{l'}{l_0}\right)^3 \left(1 - \frac{l'}{l_0}\right) \qquad \text{II.}$$

For the elasticity at 0° centigrade in Table XII. the equation,

$$\frac{mE_0}{D_0} = \frac{4\,\frac{l'}{l_0} - 3}{\left(1 - \frac{l'}{l_0}\right)^3} \times 7.544 \times 10^9 \qquad \text{III.}$$

was employed, being obtained by dividing equation (4) of § 13 by equation (5) of the same section, and substituting the values of the constants.

For the latent heat, in Table XIII., calculated at intervals of 10° from 0° to 150°, the fundamental equation I. of § 3 was used in the form,

$$\frac{Lm}{K} = 1.974\,T \div \left(1 - \frac{l'}{l}\right) \qquad \text{IV.}$$

Finally the difference of the specific heats in the liquid state under constant pressure and under constant volume is calculated in Table XIV. for the same intervals, by a

formula derived from the fundamental equation and from equations (3) and (5) of § 13, namely,

$$\frac{(H-H')\,m}{K} = 5.922 \div \left(4\,\frac{l'}{l} - 3\right) \qquad \text{V.}$$

For curiosity's sake, Table XV. was also constructed to show the surface tension at intervals of 10° corresponding to a given ratio of l' to l. It was assumed that the density varied as the quotient of the absolute molecular weight by the cube of the absolute molecular distance; and having determined the value of l for water (about .000,000,01), we have from § 13, IV. and (4), approximately,

$$S\sqrt[3]{\frac{m^2}{D^2}} = 30 \div \left(1 - \frac{l'}{l}\right)\frac{T}{T_0} \qquad \text{VI.}$$

by which the value of S may be calculated roughly from that of $l' \div l$, and conversely.

In the construction of the last three tables it was necessary to calculate the ratio, $l' \div l$, at various temperatures, in terms of its value at 0°, which might have been done indirectly by means of Table X. and Table III. — the ratio varying inversely as the cube root of the volume. To facilitate this calculation, however, an *auxiliary table* was constructed (XVI.), by means of which, if the ratio of l' to l is known at any one temperature, it may be found at any other.

It is easy by means of these tables to find the values of all of the six specific constants of this section, when *any one* is given. By reference to the proper table, the ratio of l' to l_0 can be found, already reduced to the temperature zero; then with this as an argument, the values of the other constants can be derived, each from its own table. It is assumed that the density and molecular

weight are known, and also the quantivalence of the various atoms which compose the molecule.

To present the results of the theory in the clearest form, and in the smallest possible compass to compare them with those of observation, Table XVIII. has been constructed; the old-fashioned names of the substances, which are exclusively liquids, are placed in the first column; the most modern symbols follow, and to still further identify the liquids, the density, boiling point and melting point are added, mostly from the determinations of Kopp and Pierre. The value of the Principal Argument, $l' \div l$, is then tabulated in three columns, calculated respectively from the expansion, the critical temperature and the latent heat.* The last column contains references to the tables or sections where the liquid in question has received a special examination, so that the comparison may easily be made.

The truth of the theory is illustrated by the general agreement of the values of the Principal Argument calculated from different data; its practical use is limited only by the accuracy with which, from the most probable value of the Argument, the various constants may be derived.

§ 16. The treatment of the specific heat of gases, the tension of vapors and the expansion of liquids subject to a change of state involves the use of the theory of probability, which is foreign to the purpose of this paper. It seemed, however, desirable to show that there was nothing in these phenomena necessarily inconsistent with the law which we have assigned to the variation of the force of cohesion.

The similarity between a *velocity* in the kinetic theory and an *accidental error* in the theory of probability is seen from various considerations. Knowing only, in any spe-

* Calling unity the value of K.

cial case, that the velocity or error is positive and finite, we are able, nevertheless, to calculate from various data the average, the mean, and the probable value. The chances are the same for positive as for negative magnitudes, and the principle of the conservation of energy requires that velocities taken at random, like errors, shall be compounded so that the mean square of the resultant may be equal to the sum of the mean squares of the components.

If we possessed absolutely no knowlege of the mechanism by which velocities are determined, our only choice would be to apply the same rules as to accidental errors; and by comparing the different formulae which have been suggested for the kinetic theory, one might easily become convinced that the substitution of one formula for another is not likely to cause a mistake of more than one place in the decimal point.

The formula for the probability (ϕc) of a velocity of a *gas* molecule, for instance, being less than c, may be deduced from Watson's formula, in his *Kinetic Theory of Gases*, page 5, namely,

$$\phi c = \frac{4h^{\frac{3}{2}}}{\sqrt{\pi}} \int_0^c e^{-hcc} c^2 dc,$$

while Chauvenet's formula for the probability that an error will be less than t is

$$\phi t = \frac{2}{\sqrt{\pi}} \int_0^t e^{-tt} dt.$$

The formulae for solids and liquids have not apparently been worked out, and, in complete ignorance of the mechanism which determines the kinetic energy of a given particle, we can obtain an approximation, only, to the distribution of velocities, by means of the more general theory of probability. For convenience of reference, a table of the probability of errors has been appended, calculated by

Chauvenet, from 0 to 5 times the probable error; and Mr. Haskell has extended this table in logarithms from 5 to 100 times the probable error. It will therefore be an easy matter to calculate, roughly, the chances of all the different velocities which are likely to occur, and to see whether the various phenomena, such as have been described, can be attributed to the inequality of their distribution according to the laws of chance. The results must be accepted with the greatest caution, as indicating the possibility of explaining the phenomena in this way, and not the probability of having found the true solution.

The internal molecular heat has been so successfully treated of late, by the ordinary assumptions of the Kinetic Theory, that there can be little or no question that the subject is properly a branch of this theory, and consequently, being entirely independent of cohesion, cannot conflict with any supposition as to the nature of the latter.

The question of vapor tensions needs a special examination.

Maxwell has pointed out in his *Theory of Heat*, under the "Molecular Theory of Evaporation and Condensation" (page 323), that a liquid in contact with its vapor is in equilibrium when the rate of evaporation of the liquid is equal to the rate of condensation of the vapor, both being determined by the laws of chance.

By assuming that the total energy of a substance varies as the square of a velocity, we may at once obtain expressions for the probability of a particle of water becoming steam and a particle of steam becoming water, taking into account the interchange across any surface which separates them. The theoretical solution will be of the general form,

$$\left(\frac{D'}{D}\right)^{n} = A^2 \left(prob^{-1}\ co\text{-}prob\ \frac{1}{A}\sqrt{1 + \frac{L}{W}}\ \right)^2 \times \left(\frac{BKT}{Lm}\right);$$

the demonstration of this formula (which is itself of slight importance) will be omitted on account of its length. *A*

is the ratio of the probable to the mean velocity, and B may be taken as 1.974; W is the total energy contained in the substance; and n is nearly equal to unity. The formula indicates, in a general way, the variation of vapor tension with the temperature and in different substances. Solved by the ordinary tables of probability, its results may vary widely from the truth (though seldom by more than one decimal place), which is in part owing to the uncertainty of the true value of W. Were there a table constructed to represent the actual probability of a velocity bearing various ratios to the probable velocity, one might reasonably expect to obtain more accurate results.

The theory of probability throws much light on the subject of the expansion of liquids near their melting point.

In the solid or crystalline state, bodies may occupy more or less space than in a state of fusion, according to circumstances; and we conclude that there must exist certain molecular arrangements which are more compact, and others less compact, than a simple chance distribution.*

Whenever a particle contains two or more molecules having, as a system, sufficient velocity to overcome their mutual cohesion, the particle may be said to be in a state of fusion; if, on the other hand, their velocity is so slight that the molecules must return to the same relative positions, the particle may be considered to be solid.

The principle of the distribution of velocities asserts that in any substance in which the mean velocity is given, there are always a certain number of molecules which have, for the moment, more than twice that velocity, for instance; that no matter how high the temperature may be raised, through the inequalities of chance, there will always be *some* molecules whose relative velocities are

* A homely illustration might be derived from architecture, in which the general structure is less aggregated, and the solid portions more so, than the materials would be if completely disarranged.

insufficient, for the time being, to carry them out of the sphere of their mutual attraction; and that no matter how low the temperature may be, there will always be *some* which are free to move under the influence of external forces.*

It follows that in liquids, solid particles, in solids, liquid particles must always be present.

What distinguishes a solid from a liquid is not, therefore, according to this theory, the fact that all particles are either solid or liquid; but simply that the rate of solidification or of liquefaction, as the case may be, is in excess; so that a structure once set up is capable, in solids, of maintaining itself, while in liquids it never attains more than indefinitely small dimensions.

The existence, however, of an indefinite number of these indefinitely small solid particles is easily seen to have a marked influence on the volume whenever in the solid state the density is considerably different from that of the liquid.

Conspicuous amongst all liquids in this respect stands water, which expands greatly on solidifying. In all such liquids, the continual formation of solid particles, be it only for an instant, must tend to increase the volume, and the colder the liquid becomes, the greater will be the proportion of solid particles at any instant; so that, other things being equal, the liquid will expand by cooling.

On the other hand, if the solid be denser than the liquid, the rate of expansion with the temperature will be increased by the gradual disappearance of solid particles.

The existence, therefore, of exceptions to the general law of expansion does not militate in any way against the validity of the reasoning by which it was established.

As in the case of vapor tensions, the quantitative application of the theory of probability is beset with mathe-

* The practical effect is seen, undoubtedly, in the slow yielding of the hardest rocks to enormous pressures, discussed in Geology, and in the so-called viscosity of ice.

matical difficulty and practical objections. It may perhaps be allowable to suggest that, from almost any point of view, there will be in melting ice only from fifty to seventy per cent. of solid particles, and in freezing water nearly one-half as many, but in boiling water not more than one-third; so that the number which disappear in melting is not more than twice the number which are eliminated when the liquid is raised to boiling. The true expansion, therefore, from 0° to 100°, instead of being 1.04, may be from 1.08 to 1.10, and the real coefficient at 0° is probably from .0006 to .0008, increasing regularly with the temperature, as in the case of an ordinary liquid.

§ 17. The investigation of the hypothesis that the cohesive forces vary inversely as the 4th power of the distance has now been carried as far as was originally intended. The results of other hypotheses remain to be determined.

In equation IV. § 2,

$$JLD = \frac{3}{a-1}\,(\bar{P} + E\epsilon T),$$

If a different value be assigned to a, we can see that the relation between the latent heat and the other constants will be materially altered. There being no reason on the whole to suppose that the value already considered is either too great or too small, and since a determines, in a certain way, the *average* rate of change of the cohesion, it follows that we are not allowed any great width in the nature of our fundamental hypothesis.

It is not so with the cohesion at short distances. In the condition of equilibrium,

$$\bar{P} + P' + \bar{P}'' = 0,$$

if we write $P'' : P_0'' = l_0^x : l^x$, we shall obtain equations as before for the elasticity and the expansion, which may be

at once reduced to the forms already obtained by putting $x = 6$.*

We have

$$E = \frac{P'}{3}\left[\frac{3l - 2l'}{l - l'} + l \log \frac{l_0}{l} \frac{dx}{dl} - x\right]$$

$$+ \frac{\overline{P}}{3}\left[l \log \frac{l_0}{l} \frac{dx}{dl} - x\right] \qquad \text{I.}$$

$$\epsilon = \frac{3\left[1 - \frac{\overline{P}}{3E}\left(l \log \frac{l_0}{l} \frac{dx}{dl} - x\right)\right]}{T\left[\frac{3l - 2l'}{l - l'} + l \log \frac{l_0}{l} \frac{dx}{dl} - x\right]} \qquad \text{II.}$$

whence, by substitution, we shall find $E\epsilon\, T = P_1'$ as before.

Disregarding P in comparison with E or P', and treating x as a constant, we have by differentiation,

$$\frac{d\epsilon}{dT} = \frac{\epsilon^2}{3}(x - 3)\frac{\left[\frac{x-2}{x-3}\right]^2\left[\frac{3 + (x-3)\,\epsilon T}{3 + (x-2)\,\epsilon T}\right] - 1}{\left[\frac{x-2}{x-3}\right]\left[\frac{3 + (x-3)\,\epsilon T}{3 + (x-2)\,\epsilon T}\right] - 1}$$

$$= \frac{\epsilon^2}{9}\left(6x - 15 + \epsilon T\left(x^2 - 5x + 6\right)\right) \qquad \text{III.}$$

$$\frac{d^2\epsilon}{dT^2} = \frac{\epsilon^3}{81}\left\{\begin{array}{l} 2(6x - 15 + T\epsilon(x^2 - 5x + 6))^2 + 9(x^2 - 5x + 6) \\ + T\epsilon(x^2 - 5x + 6)(6x - 15 + T\epsilon(x^2 - 5x + 6)) \end{array}\right\} \text{IV.}$$

etc.

From equations III. it is easily seen that x cannot be constant and less than 3, since it is well known that the rate of expansion increases with the temperature.

There is much however to indicate for x a smaller value than 6; the rate of expansion does not increase quite so rapidly on the whole as our first analysis would indicate, and from the analogy of small magnets we should expect that at short distances the attraction should vary, for compound substances, inversely as some power of the distance be-

* It will be noticed that the value of x is here greater by 2 units than in § 2, denoting the rate of variation of the pressure, not the attraction.

tween the fourth and the square; that is, we should expect to find $6 > x > 4$.

The effect of diminishing x will be evidently to increase the elasticity and to diminish the expansion in like proportion, so that the product $E\epsilon T$ will not be affected, and hence the principal ratio, K, will remain the same; but the specific heat, which involves the product $E\epsilon^2 T$, will be diminished, as we have already seen is the case in solid bodies.

A diminution of x would, however, increase the calculated value of the critical temperature, which we have seen is already too high, and this alone is sufficient to counterbalance the weight of the argument founded upon expansion.

By giving different values to x, all possible relations may be represented between ϵ and its derivative; by assigning arbitrary values to x at different temperatures, any law of expansion can be expressed; and if our reasoning has been correct, when the true relations between the derivatives shall have been determined with still greater accuracy than at present, we shall be able to conclude precisely by what law the cohesion actually varies in different states of aggregation, and we may then class under the head of accurate knowledge what has so far been only hypothetical.

§ 18. The above sections were already in the press when the communication of D. Mendelejeff, *On the Expansion of Liquids*, published in the April Journal of the Chemical Society at London, first came to my notice. The table for the expansion of liquids, quoted from Thorpe, has been reprinted in full (Table VIII.) and is a most striking confirmation of the uniformity of the law of expansion of liquids, pointed out in § 9. One can hardly avoid the conclusion that the experiments of Thorpe must

have been remarkably free from sources of accidental error.

Mendelejeff points out that the law of expansion may be represented, within the limit of error of observation, by the extremely simple empirical formula,

$$V_t = \frac{1}{1 - kt},$$

where k is a constant very nearly equal to the coefficient of expansion.

By calculating k for the next to the highest temperature in the table, I find an average error of only five ten-thousandths in the use of this formula for the 47 liquids examined by Thorpe. The formula claims, therefore, a careful investigation.

Differentiating and dividing by the volume, we have

$$\epsilon = \frac{dV}{Vdt} = \frac{k}{1 - kt} \qquad \text{I.}$$

$$\frac{d\epsilon}{dt} = \frac{k^2}{(1 - kt)^2} = \epsilon^2 \qquad \text{II.}$$

$$\frac{d^2\epsilon}{dt^2} = 2\epsilon^3 \qquad \text{III.}$$

$$\frac{d^n\epsilon}{dt^n} = n!\,\epsilon^n, \text{ etc.}$$

The first derivative is therefore only about one-third as great as the Theory would indicate, and the other derivatives are also much smaller, so that the isobaric curves will be straighter; but from Table VII. it will be sufficiently evident that the whole difference in question is less than the mean difference between two observers such as Kopp and Pierre.

From a purely empirical point of view, it is not easy to decide between the relative values of the formula of Mendelejeff and that of the Theory.

In the case of the 47 liquids examined by Thorpe, it must be frankly admitted that although the observed values lie, in every case but one, between those calculated by the two formulae, the average is twice as near the indication of Mendelejeff as to that of the Theory. More significance would, however, be attached to this fact, were there a sufficient number of observations, made independently, with which the results of Thorpe might be compared. The curvature of the line representing the expansion is subject to a constant error due to the standards of comparison; and the fact that nearly every other observer has found a greater curvature, not only for liquids in general, but also for those few examined in common with Thorpe, should not be left out of account.

For the purpose of comparison, Table IX. was constructed, showing the differences between the volumes according to Mendelejeff's formula and those from the mean results of Kopp and Pierre, for the eleven liquids already examined.

It will be noticed that the volumes for ether do not agree with those calculated by Mendelejeff, owing probably to the use of other data by the same observers, which I have not been able to discover. The figures taken from Sharples' Tables are not so favorable as those quoted in the paper. The sums of the squares of the differences are represented in the table below.

If, for various reasons, butyric acid be omitted from the list, the sums of the squares of the errors will be 2,432,832 for Kopp and Pierre, 2,289,662 for Mendelejeff, and 414,460, for the Theory; or, throwing out fusel-oil, which is most unfavorable to Mendelejeff, the sums will become 1,551,256, 736,953, and 243,518, respectively.

The statement of Mendelejeff, that the empirical formula represents the expansion within the limit of error of observation, is therefore completely borne out in the case

Name of the Liquid.	No. of Temperatures compared.	Sum of the squares of the differences between Kopp and Pierre. (See Table VII.)	Do. between Mendelejeff's formula and their mean. (See Table IX.)	Do. between the Theory and their mean. (See Table VII.)
1. Wood Spirit.	6	358,654	6,379	8,947
2. Alcohol.	7	22,416	24,150	2,986
3. Ether.	3	2,390	2,837	221
4. Aldehyde.	2	114,225	3,249	569
5. Acetate of Ethyl.	7	226,751	90,236	2,180
6. Acetate of Methyl.	5	32,854	16,783	598
7. Formate of Ethyl.	5	13,181	7,722	5,455
8. Fusel-oil.	14	881,576	1,552,709	170,942
9. Butyrate of Methyl.	10	374,221	142,927	145,801
10. Butyrate of Ethyl.	11	406,564	442,670	76,761
11. Butyric Acid.	15	377,433	78,600	1,242,141
Total	85	2,810,265	2,368,262	1,656,601

of these eleven liquids, whether we reject certain of them or not; it is equally obvious that our own formula here affords a still closer approximation. In the case of the seventy-five liquids of Table VII., it will be found that the average ratio between the coefficients, *A*, *B* and *C*, corresponds a little more closely to the Theory than to the empirical formula, being nearly midway between the two.

There are not sufficient data to prove that either formula may not be absolutely true; but the indication of such

facts as we possess is that the truth must lie between them.

It was pointed out in § 10 that, in expansion, the free path would increase with the distance *more* than one might expect, by an amount which could be calculated, for instance, in the case of spherical atoms.

The impact, which is necessarily central in the most condensed state, would often be oblique in a state less condensed. The effect of thus increasing the length of the free path would be to diminish the visible expansion and also its rate of change. The same is true of the rapidly increasing vapor tension, and these considerations, together with those given in the last section, are sufficient to account for a much greater difference than actually exists between the theoretical and empirical formulae.

The latter is undoubtedly, as Mendelejeff claims, a *first approximation* to the expression of the facts; the former, to their exact theoretical solution. The close agreement of the formulae must be considered as a mutual confirmation.

§ 19. In the same April Journal of the Chemical Society will be found an article by Thorpe and Rücker *On a Relation between the Critical Temperatures of Bodies and their Thermal Expansions as Liquids.*

The formula of Van der Waals is first considered, namely, that *at corresponding temperatures,*

$$\frac{1}{V_t}\,\frac{dV_t}{dt} \times T_1 = C, \qquad \text{I.}$$

in which the first factor is evidently the same as our ϵ. This formula, by the way, may be derived from § 13.

In (6) we have

$$\left(\frac{l'}{l}\right)^3 \left(1 - \frac{l'}{l}\right) = .11875\,\frac{T}{T_1}\,\frac{(P' + \bar{P})}{P'}$$

where, neglecting the last factor, which is nearly equal to 1, we see that if we know the ratio of T_1 to T, which is

the same, by definition, for all liquids at *corresponding temperatures*, the ratio of l' to l must be determined. We have, therefore, for the coefficient of expansion, from (5),

$$\epsilon = \frac{3}{T} \frac{1 - \frac{l'}{l}}{4\frac{l'}{l} - 3},$$

where we see that if $\frac{l'}{l}$ is given, ϵ varies inversely as the temperature.

Therefore $\epsilon : \epsilon' = T' : T = T_1' : T_1$, or $\epsilon T_1 =$ constant.

By combining this result with Mendelejeff's formula for expansion,

$$V_t = \frac{1}{1 - kt},$$

Thorpe and Rücker obtain the following:

$$\frac{V_0}{V_t} = \frac{aT_1 - T}{aT_1 - 273}, \qquad \text{II.}$$

whence

$$a = \frac{TV_t - 273}{T_1(V_t - 1)} \qquad \text{III.}$$

The mean value of a is calculated for 7 liquids, the critical temperature being determined by Sajotschewsky, as 1.995; from 5 other determinations, 1.976; from 10 by Pawlewski, 1.991; and from 12 others, 1.93. Selecting the most probable value, 1.995, the critical temperatures of the first 7 liquids are calculated by the formula,

$$T_1 = \frac{TV_t - 273}{1.995\,(V_t - 1)}, \qquad \text{IV.}$$

with a remarkable degree of approximation, the average error being very little more than one degree, which is of

course very much smaller than the probable error of observation.

Table XVII. has been constructed to show the probable error when *all* the liquids quoted are taken into account, and to compare this error with that of the Theory. It will be seen that the average error is here in the tens and not in the units, and that the probable error of the Theory is a little smaller, and could be made very much so, had it been thought advisable to introduce the empirical constant, 0.116, instead of that calculated from purely theoretical considerations (.11876).

The use of either formula is of practical importance, and the difference between their indications is no greater than the limit of error of observation. This is owing to the close agreement, at low temperatures, of the formulae for expansion (already considered), by which, in combination with the principle of Van der Waals, the critical temperature might be calculated in each case.

Both formulae agree in indicating, for all liquids, an invariable ratio between the densities at the absolute zero and at the critical temperature. From the empirical formula (II.), we see that this ratio should be $a \div (a - 1)$, or 2.005, nearly, while the Theory requires the cube of $l_1 \div l_1'$ or about 3.4. Various considerations, whose discussion would be unprofitable, tend to diminish this theoretical value; but a single accurate determination of the density of a liquid in the critical state would probably serve as a crucial test of the reasoning.

§ 20. Conclusion:—(1) It is not claimed that the theory which has been developed is by any means a complete solution of the relations existing between the various constants of Thermodynamics; the main point has been to show that such relations exist. The provisional assumption of a cohesive force varying inversely as the fourth

power of the distance may be considered as the first link in the chain by which these may finally be connected together.

(2) The connection between these constants is exemplified in a series of six tables, in which they are all expressed, explicitly or implicitly, in terms of certain well-known constants, and one which is peculiar to this theory, called the Principal Argument. It has not been attempted to adjust these tables empirically (which might easily have been done) so as to obtain the best possible results; they represent rigidly the relation between the six physical constants required by the Theory for an ideal liquid or solid.

(3) The indications of this theory are in many cases within the limits of errors of observation, and in no case are we led to a result which is not reasonably close to the truth, considering the quantities which have been neglected. The same would not have been true if any fundamental change had been made in the supposition as to the nature of the cohesive force or its rate of variation, the general law for which may, therefore, be considered as established.

(4) In view of the magnitudes of several of the quantities treated, the approximate agreement of the results precludes any essential error in the formulae.

(5) In working out the mathematical solution of various problems, we had frequent recourse to certain formulae which were already developed in Maxwell's *Electricity and Magnetism.* We have followed, all through, the analogy between the attraction of a number of small magnetized spheres and the ordinary phenomena of cohesion. The analogy appears to hold in every respect. On the other hand, the laws of the attraction assigned to ordinary unpolarized matter have been proved to be entirely incompatible with the known facts.

(6) There being nothing inconsistent with any of the phenomena known to Chemistry or Physics in the supposition that the ultimate particles of matter, of whatsoever sort, have fundamentally the same characteristics, may it not be that the same causes which, under certain conditions, render the particles of steel and other substances permanently magnetic, belong in reality to the elementary atoms of which all bodies are composed, like the polarities assigned to them in electrolysis, whether the body as a whole exhibits magnetic or diamagnetic properties? If this should be so, then we have found the physical basis for a Theory of Cohesion.

TABLES.

Table of the Probability of Errors. (Probable Error = 1.)

Derived from Chauvenet's Astronomy, Vol. II, Table IX, A

Error less than	Probability.	Difference for 0.01	Error greater than	Probability.	Difference for 0.01
0.0	0.00000	.00538	2.5	0.09175	.00129
0.1	0.05378	.00537	2.6	0.07949	.00115
0.2	0.10731	.00533	2.7	0.06859	.00102
0.3	0.16035	.00527	2.8	0.05895	.00090
0.4	0.21268	.00519	2.9	0.05046	.00079
0.5	0.26407	.00509	3.0	0.04302	.00069
0.6	0.31430	.00496	3.1	0.03654	.00060
0.7	0.36317	.00481	3.2	0.03090	.00052
0.8	0.41052	.00465	3.3	0.02603	.00045
0.9	0.45618	.00448	3.4	0.02183	.00038
1.0	0.50000	.00429	3.5	0.01824	.00033
1.1	0.54188	.00407	3.6	0.01518	.00028
1.2	0.58171	.00388	3.7	0.01257	.00024
1.3	0.61942	.00367	3.8	0.01038	.00020
1.4	0.65498	.00345	3.9	0.00853	.00017
1.5	0.68833	.00324	4.0	0.00698	.00014
1.6	0.71949	.00301	4.1	0.00569	.00012
1.7	0.74847	.00279	4.2	0.00461	.00009
1.8	0.77528	.00258	4.3	0.00373	.00008
1.9	0.79999	.00237	4.4	0.00300	.00007
2.0	0.82266	.00217	4.5	0.00240	.00005
2.1	0.84335	.00197	4.6	0.00192	.00004
2.2	0.86216	.00179	4.7	0.00152	.00003
2.3	0.87918	.00162	4.8	0.00121	.00003
2.4	0.89450	.00146	4.9	0.00095	.00002
2.5	0.90825	.00130	5.0	0.00074	.00002

Table of the Logarithmic Probability of Errors.

Probable Error = 1. (Haskell.)

Error greater than	Logarithm of Probability.	Difference.	2nd Difference.
5.0	$\bar{4}.8722$	.2165	
5.2	$\bar{4}.6557$	.2239	74
5.4	$\bar{4}.4318$	.2314	75
5.6	$\bar{4}.2004$	.2389	75
5.8	$\bar{5}.9615$	.2464	75
6.0	$\bar{5}.7151$	.2540	76
6.2	$\bar{5}.4611$	.2615	75
6.4	$\bar{5}.1996$	.2691	76
6.6	$\bar{6}.9305$	.2767	76
6.8	$\bar{6}.6538$	.2843	76
7.0	$\bar{6}.3695$	.2919	76
7.2	$\bar{6}.0776$	.2995	76
7.4	$\bar{7}.7781$	.3072	77
7.6	$\bar{7}.4709$	.3148	76
7.8	$\bar{7}.1561$	.3226	78
8.0	$\bar{8}.8335$	.3302	76
8.2	$\bar{8}.5033$	.3379	77
8.4	$\bar{8}.1654$	.3455	76
8.6	$\bar{9}.8199$	.3532	77
8.8	$\bar{9}.4665$	.3609	77
9.0	$\bar{9}.1056$	.3686	77
9.2	$\overline{10}.7370$	.3764	78
9.4	$\overline{10}.3606$	.3842	78
9.6	$\overline{11}.9764$	.3919	77
9.8	$\overline{11}.5845$	.3996	77
10.0	$\overline{11}.1849$		78

Logarithmic probability continued, accurate to four figures.

Error greater than	Logarithm of Probability.	Difference.	2nd Difference.
10	$\overline{11}.185$	2.115	
11	$\overline{13}.070$	2.309	194
12	$\overline{16}.762$	2.504	195
13	$\overline{18}.258$	2.699	195
14	$\overline{21}.559$	2.894	195
15	$\overline{24}.665$	3.090	196
16	$\overline{27}.575$	3.286	196
17	$\overline{30}.289$	3.482	196
18	$\overline{34}.807$	3.678	196
19	$\overline{37}.129$	3.865	197
20	$\overline{41}.254$		

Logarithmic probability continued, containing four significant figures.

Error greater than	Logarithm of Probability.	Difference.	2nd Difference.
10	$\overline{11}.18$	29.93	
20	$\overline{41}.25$	49.57	19.64
30	$\overline{91}.68$	69.27	19.70
40	$\overline{160}.41$	89.01	19.74
50	$\overline{249}.40$	108.75	19.74
60	$\overline{358}.65$	128.49	19.74
70	$\overline{486}.16$	148.25	19.76
80	$\overline{635}.91$	167.99	19.74
90	$\overline{803}.92$	187.75	19.76
100	$\overline{990}.17$		

I.

Table for Epsilon and its Derivatives.

Containing four significant figures calculated for

$T = 273°$

ϵ	$D_T\epsilon$ .0000	$D^2_T\epsilon$ .000000	$D^3_T\epsilon$ .00000000	$D^4_T\epsilon$ .0000000000
.0001	0002369	00001264	000001068	0000001239
.0002	0009624	00010470	000018040	0000042700
.0003	0021980	00036540	000096300	0000349000
.0004	0039660	00089500	000320400	0001581000
.0005	0062880	00180500	000824200	0005180000
.0006	0091860	00322100	001797000	0013820000
.0007	0126800	00527900	003501000	0032000000
.0008	0167900	00812600	006273000	0066760000
.0009	0215500	01193000	010550000	0142600000
.0010	0269700	01687000	016850000	0232500000
.0011	0330900	02313000	025870000	0399500000
.0012	0398900	03091000	038370000	0658000000
.0013	0474400	04046000	054630000	1045000000
.0014	0557300	05199000	077300000	1611000000
.0015	0647100	06577000	107300000	2417000000
.0016	0746400	08206000	145000000	3544000000
.0017	0853300	10110000	192900000	5093000000
.0018	0968300	12340000	253000000	7185000000
.0019	1092000	14900000	327600000	9972000000
.0020	1225000	17610000	419200000	13643000000

II.

Table of Coefficients of Volume.

Containing four significant figures.

$$V = 1 + at + bt^2 + ct^3 + dt^4 + et^5 + \&c.$$

a .00	*b* .00000	*c* .0000000	*d* .000000000	*e* .00000000000
01	001684	00003458	0000007892	00000001498
02	006812	00028400	0000131900	00000051100
03	015490	00098370	0000697200	00000413300
04	027830	00239100	0002299000	00001854000
05	043940	00478800	0005851000	00006020000
06	063930	00848400	0012640000	00015930000
07	087900	01381000	0024410000	00036560000
08	115900	02111000	0043350000	00075630000
09	148200	03079000	0072290000	00156000000
10	184800	04327000	0115000000	00263800000
11	225900	05897000	0174500000	00442600000
12	271400	07833000	0256900000	00724000000
13	321700	10190000	0364500000	01142000000
14	376600	13020000	0511100000	01748000000
15	436000	16370000	0702300000	02608000000
16	501200	20320000	0943100000	03801000000
17	571100	24910000	1246000000	05435000000
18	646100	30250000	1621000000	07626000000
19	726500	36340000	2089000000	10530000000
20	812500	42930000	2651000000	14300000000

III. TABLE OF VOLUMES.

Significant to four decimal places besides the zeros preceding.

VOLUME AT $0° = 1.000000$.

ϵ	−10°	10°	20°	30°	40°	50°	60°	70°
.0001	0.999002	1.001002	1.002007	1.003015	1.004027	1.005042	1.006062	1.007084
.0002	0.998007	1.002007	1.004027	1.006062	1.008109	1.010170	1.012260	1.014340
.0003	0.997015	1.003015	1.006063	1.009142	1.012260	1.015400	1.018580	1.021790
.0004	0.996028	1.004028	1.008113	1.012260	1.016470	1.020730	1.025070	1.029450
.0005	0.995044	1.005044	1.010180	1.015410	1.020730	1.026160	1.031690	1.037320
.0006	0.994063	1.006065	1.012270	1.018600	1.025070	1.031720	1.038500	1.045450
.0007	0.993087	1.007089	1.014360	1.021830	1.029510	1.037400	1.045490	1.053850
.0008	0.992114	1.008118	1.016480	1.025100	1.034000	1.043180	1.052700	1.062510
.0009	0.991145	1.009151	1.018610	1.028420	1.038590	1.049140	1.060110	1.071520
.0010	0.990180	1.010180	1.020770	1.031790	1.043270	1.055240	1.067750	1.080880
.0011	0.989210	1.011230	1.022950	1.035200	1.048030	1.061510	1.075660	1.090580
.0012	0.988260	1.012280	1.025150	1.038670	1.052920	1.067940	1.083850	1.100700
.0013	0.987310	1.013330	1.027380	1.042210	1.057900	1.074580	1.092340	1.111300
.0014	0.986370	1.014390	1.029620	1.045780	1.063010	1.081410	1.101200	1.123400
.0015	0.985420	1.015460	1.031880	1.049430	1.068240	1.088470	1.110400	1.134100
.0016	0.984480	1.016520	1.034180	1.053150	1.073600	1.095780	1.120000	1.146500
.0017	0.983550	1.017590	1.036500	1.056920	1.079110	1.103300	1.130000	1.159400
.0018	0.982620	1.018680	1.038850	1.060780	1.084770	1.111200	1.140500	1.173300
.0019	0.981690	1.019770	1.041230	1.064720	1.090590	1.119300	1.151500	1.187900
.0020	0.980770	1.020850	1.043630	1.068710	1.096580	1.127800	1.163000	1.203300

III. TABLE OF VOLUMES (continued).

Significant to four decimal places besides the zeros preceding.

VOLUME AT 0° = 1.000000.

ϵ	80°	90°	100°	110°	120°	130°	140°	150°
.0001	1.008110	1.009136	1.01017	1.01120	1.01225	1.01329	1.01433	1.01539
.0002	1.016450	1.018570	1.02068	1.02286	1.02503	1.02721	1.02943	1.03163
.0003	1.025040	1.028320	1.03166	1.03501	1.03841	1.04166	1.04534	1.04886
.0004	1.033910	1.038440	1.04304	1.04772	1.05247	1.05731	1.06222	1.06720
.0005	1.043080	1.048950	1.05494	1.06106	1.06729	1.07367	1.08017	1.08686
.0006	1.052580	1.059890	1.06738	1.07509	1 08297	1.09108	1.09944	1.10800
.0007	1.062450	1.071310	1.08045	1.08990	1.09964	1.10970	1.12020	1.13100
.0008	1.072700	1.083250	1.09421	1.10560	1.11740	1.12970	1.14260	1.15600
.0009	1.083420	1.095810	1.10880	1.12330	1.13650	1.15150	1.16710	1.18370
.0010	1.094610	1.109300	1.12420	1.14030	1.15720	1.17490	1.19390	1.21400
.0011	1.106300	1.123000	1.14060	1.15940	1.17940	1.20080	1.22360	1.24790
.0012	1.118700	1.137800	1.15820	1.18020	1.20370	1.22910	1.25650	1.28600
.0013	1.131700	1.153600	1.17710	1.20260	1.23030	1.26040	1.29320	1.32900
.0014	1.145500	1.170400	1.19750	1.22720	1.25960	1.29540	1.33450	1.37780
.0015	1.160100	1.188300	1.21960	1.25650	1.29220	1.33450	1.38140	1.43370
.0016	1.175600	1.207800	1.24360	1.28350	1.32830	1.37830	1.43460	1.49810
.0017	1.192300	1.228900	1.26990	1.31630	1.36850	1.42800	1.49550	1.57200
.0018	1.210000	1.251400	1.29860	1.35250	1.41390	1.48430	1.56490	1.65750
.0019	1.229200	1.276200	1.33030	1.39810	1.46490	1.55700	1.64490	1.75700
.0020	1.249600	1.302900	1.36490	1.43720	1.52180	1.62040	1.73580	1.87050

TABLE IV.

Containing four significant figures.

	−10°			0°			10°		
	A	B	C	A	B	C	A	B	C
ε	.00	.00000	.0000000	.00	.00000	.0000000	.00	.00000	.0000000
.0001	0100	001684	00003411	0100	001684	00003458	0100	001684	00003505
.0002	0200	006807	00027620	0200	006812	00028400	0200	006807	00029200
.0003	0300	015480	00094290	0300	015490	00098370	0300	015480	00102600
.0004	0400	027800	00225800	0400	027830	00239100	0400	027800	00253400
.0005	0500	043880	00445200	0500	043940	00478800	0500	043880	00515400
.0006	0600	063800	00776500	0600	063930	00848400	0600	063780	00928300
.0007	0700	087650	01244000	0700	087900	01381000	0700	087610	01536000
.0008	0800	115500	01871000	0800	115900	02111000	0800	115500	02391000
.0009	0900	147500	02684000	0900	148200	03079000	0900	147300	03552000
.0010	1000	183700	03703000	1000	184800	04327000	1000	183300	05083000
.0011	1100	224300	04961000	1100	225900	05897000	1100	223700	07055000
.0012	1200	269000	06472000	1200	271400	07833000	1200	268200	09556000
.0013	1300	318400	0829—000	1300	321700	10190000	1300	317000	12670000
.0014	1400	372000	10390000	1400	376600	13020000	1400	370000	16530000
.0015	1500	429900	12810000	1500	436000	16370000	1500	426700	21230000
.0016	1599	493100	15610000	1600	501200	20320000	1601	488500	26930000
.0017	1699	560700	18790000	1700	571100	24910000	1701	554100	33750000
.0018	1799	632900	22430000	1800	646100	30250000	1801	623700	41890000
.0019	1899	709800	26440000	1900	726500	36340000	1901	697200	51500000
.0020	1999	791900	30590000	2000	812500	42930000	2003	774700	62410000

TABLE IV. (continued).

Containing four significant figures.

	20°			30°			40°		
	A	B	C	A	B	C	A	B	C
ε	.00	.00000	.0000000	.00	.00000	.0000000	.00	.00000	.0000000
.0001	01000	001684	00003554	01000	001683	00003603	01000	001683	00003653
.0002	02000	006806	00030030	02000	006798	00030880	02000	006787	00031770
.0003	03000	015460	00107100	03000	015410	00111800	03000	015350	00116800
.0004	04000	027720	00268600	04000	027570	00284700	04001	027360	00301700
.0005	05000	043650	00555000	05001	043260	00597600	05003	042680	00643300
.0006	06001	063290	01016000	06002	062420	01112000	06006	061100	01216000
.0007	07001	086650	01711000	07005	084890	01902000	07012	082200	02113000
.0008	08002	113700	02708000	08009	110500	03062000	08024	105500	03455000
.0009	09010	144300	04102000	09017	138500	04731000	09042	129500	05438000
.0010	10010	178400	05971000	10030	169100	06990000	10060	154500	08143000
.0011	11010	216100	08434000	11040	201400	10030000	11110	178200	11860000
.0012	12010	256600	11640000	12060	234300	14090000	12170	198400	16900000
.0013	13030	300200	15700000	13090	267100	19320000	13250	213600	23510000
.0014	14030	345700	20900000	14130	297700	26150000	14360	219500	32280000
.0015	15050	392600	27410000	15190	324200	34880000	15510	212200	43740000
.0016	16070	441500	35440000	16260	346200	45850000	16710	189200	58160000
.0017	17090	490200	45300000	17360	359700	59570000	17980	143100	76560000
.0018	18120	538200	57330000	18480	362000	76590000	19320	+0679—0	99660000
.0019	19160	584100	71930000	19650	349100	97630000	20770	—0455—0	128590000
.0020	20210	627200	89040000	20850	318400	122820000	22340	—203300	163760000

TABLE IV. (continued.)

Containing four significant figures.

	50°			60°			70°		
ϵ	A .00	B .00000	C .000000	A .00	B .00000	C .0000000	A .00	B .000000	C .0000000
.0001	01000	001682	000003704	01000	001681	00003755	01000	01680	00003808
.0002	02000	006772	000032680	02000	006753	00033610	02000	06730	00034570
.0003	03001	015270	000121900	03001	015160	00127200	03001	15020	00132700
.0004	04002	027060	000319700	04003	026680	00338600	04007	26210	00358400
.0005	05005	041880	000692000	05011	040840	00743700	05017	39550	00798300
.0006	06013	059260	001327000	06023	056860	01447000	06040	53840	01574000
.0007	07026	078450	002341000	07049	073490	02589000	07082	67220	02854000
.0008	08050	098450	003886000	08091	0938–0	04354000	08154	770–0	04859000
.0009	09089	116600	006223000	09167	0994–0	07086000	09284	771–0	08026000
.0010	10150	133400	009427000	10270	105100	10840000	10470	685–0	12390000
.0011	11230	144700	013900000	11440	0994–0	16160000	11740	+407–0	18650000
.0012	12350	146500	020070000	12670	0759–0	23600000	13160	–161–0	27490000
.0013	13530	135700	028270000	14000	+0294–0	33590000			
.0014	14770	105000	039210000	15480	–0524–0	47150000			
.0015	16120	+0473–0	053740000						
.0016	17570	–0433–0	072370000						
.0017	19150	–179200	096260000						
.0018	20940	–371700	126500000						
.0019	22940	–637700	164800000						
.0020	25210	–989500	211800000						

TABLE IV. (concluded).

Containing four significant figures.

	80°			90°			100°		
ε	A	B	C	A	B	C	A	B	C
	.00	.000000	.0000000	.00	.000000	.0000000	.00	.000000	.0000000
.0001	01000	01678	00003861	01000	01676	00003914	01000	01674	00003969
.0002	02000	06703	00035550	02001	06672	00036550	02001	06636	00037600
.0003	03003	14870	00138400	03004	14690	00144400	03005	14470	00150500
.0004	04010	25640	00379200	04014	24970	00400700	04021	24190	00423300
.0005	05027	37970	00856000	05040	36100	00916600	05057	33890	00978000
.0006	06062	50140	01710000	06093	45700	01854000	06133	40460	02005000
.0007	07129	59480	03138000	07193	50160	03439000	07278	39110	03760000
.0008	08245	623–0	05403000	08369	443–0	05984000	08532	+229–0	06604000
.0009	09452	494–0	09045000	09684	+156–0	08701000	09996	–249–0	11310000
.0010	10740	+227–0	14070000	11120	–331–0	15880000			
.0011	12190	–330–0	21350000						

Table V. — *Calculation of the mean difference between Pierre and Kopp.*

		A	B .00000	C .0000000	$\Delta^2 A$ $10^{-9}\times$	$\Delta^2 B$ $10^{-12}\times$	$\Delta^2 C$ $10^{-16}\times$
1. Wood Spirit.	P	.001185569	15649300	0911100			
	K	.001134200	13635000	0874100			
		2)+.000051369	2)+02014300	2)+0037000	2.639	0.041	0.001
		.000025685	01007150	0018500			
		.001159885	14642150	0892600			
2. Alcohol.	P	.001048630	17509900	0134518			
	K	.001041390	07836000	1761800			
		+.000007240	+09673900	−1627282	0.052	0.936	2.647
		.000003620	04836950	0813641			
		.001045010	12672950	0948159			
3. Aldehyde.	P	.001653500	85060000	6425800			
	K	.001546400	69745000	——			
		+.000107100	+15315000	——	11.471	2.346	——
		.000053550	07657500	——			
		.001599950	77402500	——			
4. Ether.	P	.001513240	23590000	4005100			
	K	.001480260	35031600	2700700			
		+.000032980	−11441600	+1304400	1.088	1.309	1.700
		.000016490	05720800	0652200			
		.001496750	29310800	3352900			
5. Formate of Ethyl.	P	.001325200	28624840	0661800			
	K	.001364460	01353800	3924800			
		−.000039260	+27271040	−3263000	1.541	7.437	10.647
		.000019630	13635520	1631500			
		.001344830	14989320	2293300			
6. Acetate of Methyl.	P	.001295950	29098000	0425690			
	K	.001277900	39471000	0363900			
		+.000018050	−10373000	+0061790	0.326	1.076	0.004
		.000009025	05186500	0030895			
		.001286925	34284500	0394795			
7. Acetate of Ethyl.	P	.001258490	29568800	1492150			
	K	.001273800	21914000	1179700			
		−.000015310	+07654400	+0312450	0.234	0.585	0.097
		.000007655	03827200	0156225			
		.001266145	25741200	1335925			

Table V. — *Calculation of the mean difference between Pierre and Kopp.*

		A	B .00000	C .0000000	Δ^2A $10^{-9}\times$	Δ^2B $10^{-12}\times$	Δ^2C $10^{-18}\times$
8. Butyric Acid.	P *	.001025700	08376000	0346900			
	P †	.001030400	08188900	0333200			
		2).002056100	2)16564900	2)0680100			
		.001028050	08282450	0340050			
	K	.001046100	05624400	0542010			
		—.000018050	+02658050	—0201960	0.326	0.071	0.041
		.000009025	01329025	0100980			
		.001037075	06953425	0441030			
9. Butyrate of Methyl.	P	.001239890	06260240	1306500			
	K	.001195650	18103000	0982920			
		+.000044240	—11842760	+0323580	1.957	1.402	0.105
		.000022120	05921380	0161790			
		.001217770	12181620	1144710			
10. Butyrate of Ethyl.	P‡	[.000632742]	[127630000]	[5027800]			
	K§	.001202790	00722338	2263460			
		.001178170	13093000	0956000			
		+.000024620	—12370662	+1307460	0.606	1.530	1.710
		.000012310	06185331	0653730			
		.001190480	06907669	1609730			
11. Fusel-oil.	P ‖	.000890100	06572900	1184580			
	P ¶	.000898850	06874460	1009600			
		.001788950	13447360	2194180			
		.000894475	06723680	1097090			
	K	.000972400	—08565100	2021800			
		—.000077925	+15288780	—0924710	6.073	2.338	0.855
		.000038962	07644390	0462355			
		.000933437	—00920710	1559455			
		Mean Difference. .0000 489---	**Mean Difference. .00000 1318----**	**Mean Difference. .0000000 1345---**	11)26.313 2.392 √23.92 489	11)19.071 1.734 √1.73.40 1318	10)17.807 1.781 √1.78.10 1345
		* 0° to 100° † 100° to 163°.4	‡ 99° to 119°.4 § +13° to 99°		‖ —15° to +80° ¶ 80° to 132°.1		

VI. Table of the Value of

No. of Liquid	A Assumed .00	A Observed .00	ΔA	B Calculated .00000	B Observed .00000	ΔB	C Calculated .0000000	C Observed .0000000	ΔC
1	0578	0576	2	0418	1347	929	015	—	—
2	0674	0674	0	0685	1721	1036	022	−005	27
3	0751	0747	4	0711	1810	1099	037	—	—
4	0783	0787	4	0741	0513	228	042	027	15
5	0802	0804	2	0617	1246	626	050	—	—
6	0804	0805	1	0760	1033	273	047	—	—
7	0813	0811	2	0455	0640	185	055	014	41
8	0820	0817	3	0944	0919	25	046	006	17
9	0824	0825	1	0449	0730	281	057	013	44
10	0827	0826	1	0770	0522	248	052	014	38
11	0837	0842	5	0610	0222	388	058	035	23
12	0838	0844	6	0770	0401	369	055	026	29
13	0841	0835	6	0955	0675	280	052	013	39
14	0861	0859	2	0770	0442	328	061	027	34
15	0888	0888	0	1134	1924	793	058	029	29
16	0895	0894	1	0771	0853	82	071	026	45
17	0909	0906	3	1166	3662	2496	062	−250	312
18	0925	0929	4	1345	3140	1795	060	−049	109
19	0928	0931	3	0771	−0063	834	080	050	30
20	0928	0934	6	1000	0307	693	075	058	17
21	0939	0940	1	1005	−0820	1825	078	081	3
22	0939	0941	2	1005	0381	624	078	049	29
23	0941	0936	5	1216	1242	26	072	−032	104
24	0941	0943	2	1216	1346	130	072	009	63
25	0951	0953	2	1233	0757	476	075	003	72
26	0952	0954	2	1538	2214	676	059	564	505
27	0955	0959	4	1420	1901	481	068	465	397
28	0962	0959	3	1250	0038	1212	078	073	5
29	0962	0965	3	1250	1231	19	078	024	54
30	0965	0962	3	1445	1865	420	071	029	42
31	0986	0979	7	1495	0967	528	076	018	58
32	0986	0985	1	1495	0608	887	076	049	27
33	0994	0994	0	1300	1090	210	088	015	73
34	0996	0993	3	1520	0625	895	079	060	19
35	0996	1000	4	1520	1738	218	079	108	29
36	1011	1009	2	0711	0333	378	083	052	31
37	1017	1017	0	1569	1576	7	085	019	66

A, B and C Calculated and Observed.

No. of Liquid	A Assumed .00	A Observed .00	ΔA	B Calculated .00000	B Observed .00000	ΔB	C Calculated .0000000	C Observed .0000000	ΔC
38	1027	1032	5	1592	1726	134	089	015	74
39	1032	1032	0	1034	0083	951	124	077	47
40	1041	1038	3	1935	1711	224	070	054	16
41	1047	1053	6	1368	1839	471	099	008	91
42	1048	1047	1	1640	1378	262	096	018	78
43	1048	1057	9	1640	0183	1457	096	096	0
44	1050	1048	2	1040	−0240	1280	119	082	37
45	1069	1071	2	1390	0033	1357	117	074	43
46	1074	1069	5	1028	0842	186	073	047	26
47	1080	1079	1	1402	1555	153	121	——	—
48	1101	1100	1	0142	0218	76	130	070	60
49	1101	1107	6	2161	4665	2504	084	−174	258
50	1114	1119	5	2047	1047	1000	104	103	1
51	1122	1121	1	1802	0170	1632	124	059	65
52	1124	1129	5	2080	4792	2712	108	−184	292
53	1132	1133	1	1822	0912	910	129	076	53
54	1141	1140	1	2323	1371	952	097	191	94
55	1141	1142	1	2323	1964	359	097	062	35
56	1150	1150	0	1451	−0090	1541	151	130	21
57	1171	1175	4	2444	3577	1133	107	−054	161
58	1175	1171	4	1903	0526	1377	149	099	50
59	1175	1172	3	2244	0501	1743	129	135	6
60	1175	1176	1	2244	1278	966	129	081	48
61	1186	1184	2	2277	0899	1378	133	135	2
62	1196	1194	2	2310	2975	665	137	−042	179
63	1196	1196	0	2310	1806	504	137	079	58
64	1200	1200	0	2714	2163	551	093	100	7
65	1206	1212	6	1964	0279	1685	164	163	1
66	1211	1212	1	2610	1778	832	120	153	33
67	1288	1286	2	2605	0514	2091	183	173	10
68	1293	1291	2	2958	0118	2840	153	213	60
69	1293	1294	1	2958	2184	774	153	409	256
70	1313	1315	2	3047	3371	324	162	——	—
71	1340	1338	2	3440	1501	1939	142	169	27
72	1351	1348	3	2793	2609	184	220	106	114
73	1400	1405	5	3700	1713	1987	165	459	294
74	1420	1415	5	3885	3315	570	137	1138	1001
75	1570	1575	5	4816	2814	2002	191	157	34

TABLE VII.

1. Wood Spirit ($\epsilon = .001120$).

	V_P	V_K	Δ_{P-K}	Δ^2	V_{P-K}	V_ϵ	$\Delta_{P,K-\epsilon}$	Δ^2
10°	1.01203	1.01149	+ 54	2916	1.01176	1.01144	+32	1024
20°	1.02442	1.02330	+112	12544	1.02386	1.02339	+47	2209
30°	1.03724	1.03549	+175	30625	1.03636	1.03589	+47	2209
40°	1.05053	1.04810	+243	59049	1.04931	1.04901	+30	900
50°	1.06436	1.06120	+316	99856	1.06278	1.06280	− 2	4
60°	1.07875	1.07483	+392	153664	1.07679	1.07730	−51	2601
				358654				8947

2. Alcohol ($\epsilon = .001020$).

	V_P	V_K	Δ_{P-K}	Δ^2	$V_{P,K}$	V_ϵ	$\Delta_{P,K-\epsilon}$	Δ^2
10°	1.01067	1.01051	+16	256	1.01059	1.01039	+20	400
20°	1.02169	1.02127	+42	1764	1.02148	1.02121	+27	729
30°	1.03309	1.03242	+67	4489	1.03275	1.03247	+28	784
40°	1.04486	1.04403	+83	6889	1.04444	1.04422	+22	484
50°	1.05701	1.05622	+79	6241	1.05661	1.05649	+12	144
60°	1.06953	1.06909	+44	1936	1.06931	1.06933	− 2	4
70°	1.08247	1.08276	−29	841	1.08261	1.08282	−21	441
				22416				2986

3. Ether ($\epsilon = .001475$).

	V_P	V_K	Δ_{P-K}	Δ^2	$V_{P,K}$	V_ϵ	$\Delta_{P,K-\epsilon}$	Δ^2
10°	1.01541	1.01518	+23	529	1.01530	1.01519	+11	121
20°	1.03152	1.03122	+30	900	1.03137	1.03131	+ 6	36
30°	1.04859	1.04828	+31	961	1.04844	1.04852	− 8	64
				2390				221

4. Aldehyde ($\epsilon = .001645$).

	V_P	V_K	Δ_{P-K}	Δ^2	$V_{P,K}$	V_ϵ	$\Delta_{P,K-\epsilon}$	Δ^2
10°	1.01745	1.01616	+129	16641	1.01680	1.01700	−20	400
20°	1.03699	1.03371	+328	107584	1.03535	1.03522	+13	169
				114225				569

TABLE VII. (continued).

5. Acetate of Ethyl ($\epsilon = .001251$).

	V_P	V_K	Δ_{P-K}	Δ^2	$V_{P,K}$	V_ϵ	$\Delta_{P,K-\epsilon}$	Δ^2
10°	1.01289	1.01297	− 8	64	1.01293	1.01282	+11	121
20°	1.02646	1.02647	− 1	1	1.02646	1.02624	+22	484
30°	1.04080	1.04051	+ 29	841	1.04065	1.04048	+17	289
40°	1.05601	1.05524	+ 77	5929	1.05562	1.05546	+16	256
50°	1.07217	1.07067	+150	22500	1.07142	1.07133	+ 9	81
60°	1.08934	1.08688	+246	60516	1.08811	1.08818	− 7	49
70°	1.10770	1.10400	+370	136900	1.10580	1.10610	−30	900
				226751				2180

6. Acetate of Methyl ($\epsilon = .001285$).

	V_P	V_K	Δ_{P-K}	Δ^2	$V_{P,K}$	V_ϵ	$\Delta_{P,K-\epsilon}$	Δ^2
10°	1.01325	1.01317	+ 8	64	1.01321	1.01317	+ 4	16
20°	1.02712	1.02717	− 5	25	1.02715	1.02705	+10	100
30°	1.04162	1.04198	− 36	1296	1.04180	1.04168	+12	144
40°	1.05677	1.05767	− 90	8100	1.05722	1.05715	+ 7	49
50°	1.07260	1.07423	−163	26569	1.07341	1.07358	−17	289
				36054				598

7. Formate of Ethyl ($\epsilon = .001294$).

	V_P	V_K	Δ_{P-K}	Δ^2	$V_{P,K}$	V_ϵ	$\Delta_{P,K-\epsilon}$	Δ^2
10°	1.01355	1.01369	−14	196	1.01362	1.01327	+35	1225
20°	1.02770	1.02764	+ 6	36	1.02767	1.02725	+42	1764
30°	1.04251	1.04210	+41	1681	1.04235	1.04200	+35	1225
40°	1.05800	1.05728	+72	5184	1.05764	1.05760	+ 4	16
50°	1.07423	1.07345	+78	6084	1.07384	1.07419	−35	1225
				13181				5455

TABLE VII. (continued).

8. Fusel-oil ($\epsilon = .00090$).

	V_P	V_K	Δ_{P-K}	Δ^2	$V_{P,K}$	V_ϵ	$\Delta_{P,K-\epsilon}$	Δ^2
−10°	0.99115	0.99017	+ 98	9604	0.99066	0.99115	− 49	2401
+10°	1.00898	1.00966	− 68	4624	1.00932	1.00915	+ 17	289
20°	1.01816	1.01927	−111	12321	1.01871	1.01861	+ 10	100
30°	1.02761	1.02894	−133	17689	1.02827	1.02842	− 15	225
40°	1.03741	1.03881	−140	19600	1.03811	1.03859	− 48	2304
50°	1.04762	1.04900	−138	19044	1.04831	1.04914	− 83	6889
60°	1.05832	1.05960	−128	16384	1.05896	1.06011	−115	13225
70°	1.06958	1.07079	−121	14641	1.07018	1.07152	−134	17956
80°	1.08148	1.08263	−115	13225	1.08205	1.08342	−137	18769
90°	1.09384	1.09522	−138	19044	1.09453	1.09581	−128	16384
100°	1.10690	1.10890	−200	40000	1.10790	1.10880	− 90	8100
110°	1.12060	1.12340	−280	78400	1.12200	1.12330	−130	16900
120°	1.13520	1.13930	−410	168100	1.13720	1.13650	+ 70	4900
130°	1.15070	1.15740	−670	448900	1.15400	1.15150	+250	62500
				881576				170942

9. Butyrate of Methyl ($\epsilon = .00114$).

	V_P	V_K	Δ_{P-K}	Δ^2	$V_{P,K}$	V_ϵ	$\Delta_{P,K-\epsilon}$	Δ^2
10°	1.01248	1.01215	+ 33	1089	1.01232	1.01165	+ 67	4489
20°	1.02515	1.02472	+ 43	1849	1.02494	1.02383	+111	12321
30°	1.03811	1.03778	+ 33	1089	1.03795	1.03659	+136	18496
40°	1.05144	1.05137	+ 7	49	1.05141	1.04998	+143	20449
50°	1.06519	1.06555	− 36	1296	1.06537	1.06408	+129	16641
60°	1.07946	1.08039	− 93	8649	1.07993	1.07894	+ 99	9801
70°	1.09435	1.09595	−160	25600	1.09515	1.09463	+ 52	2704
80°	1.10990	1.11230	−240	57600	1.11110	1.11130	− 20	400
90°	1.12620	1.12950	−330	108900	1.12780	1.12890	−110	12100
100°	1.14340	1.14750	−410	168100	1.14540	1.14760	−220	48400
				374221				145801

TABLE VII. (concluded).

10. Butyrate of Ethyl ($\epsilon = .001111$).

	V_P	V_K	Δ_{P-K}	Δ^2	$V_{P,K}$	V_ϵ	$\Delta_{P,K-\epsilon}$	Δ^2
10°	1.01206	1.01192	+ 14	196	1.01199	1.01135	+ 64	4096
20°	1.02427	1.02416	+ 11	121	1.02421	1.02319	+102	10404
30°	1.03676	1.03678	− 2	4	1.03677	1.03558	+119	14161
40°	1.04970	1.04983	− 13	169	1.04976	1.04857	+119	14161
50°	1.06317	1.06338	− 21	441	1.06327	1.06222	+105	11025
60°	1.07723	1.07745	− 12	144	1.07739	1.07656	+ 83	6889
70°	1.09233	1.09216	+ 17	289	1.09224	1.09169	+ 55	3025
80°	1.10830	1.10750	+ 80	6400	1.10790	1.10770	+ 20	400
90°	1.12540	1.12360	+180	32400	1.12450	1.12460	− 10	100
100°	1.14360	1.14050	+310	96000	1.14200	1.14250	− 50	2500
110°	1.16330	1.15810	+520	270400	1.16070	1.16170	−100	10000
				406564				76761

11. Butyric Acid ($\epsilon = .000924$).

	V_P	V_K	Δ_{P-K}	Δ^2	$V_{P,K}$	V_ϵ	$\Delta_{P,K-\epsilon}$	Δ^2
10°	1.01035	1.01052	− 17	289	1.01043	1.00940	+103	10609
20°	1.02089	1.02118	− 29	841	1.02103	1.01913	+190	36100
30°	1.03162	1.03204	− 42	1764	1.03183	1.02923	+260	67600
40°	1.04261	1.04309	− 48	2304	1.04285	1.03971	+314	98596
50°	1.05383	1.05438	− 55	3025	1.05410	1.05060	+350	122500
60°	1.06533	1.06594	− 61	3721	1.06563	1.06194	+369	136161
70°	1.07713	1.07783	− 70	4900	1.07748	1.07377	+371	137641
80°	1.08923	1.09006	− 83	6889	1.08964	1.08611	+353	124609
90°	1.10170	1.10260	− 90	8100	1.10210	1.09905	+305	93025
100°	1.11450	1.11560	−110	12100	1.11500	1.11250	+250	62500
110°	1.12760	1.12910	−150	22500	1.12830	1.12740	+ 90	8100
120°	1.14120	1.14300	−180	32400	1.14210	1.14150	+ 60	3600
130°	1.15500	1.15740	−240	57600	1.15620	1.15710	− 90	8100
140°	1.16940	1.17230	−290	84100	1.17080	1.17350	−270	72900
150°	1.18410	1.18780	−370	136900	1.18590	1.19100	−510	260100
				377433				1242141

VIII. Expansion of Liquids according to Thorpe.

(D. Mendelejeff.)

	10°	30°	60°	100°	150°
$PCl_6H_5Cl_2$	1.0083	1.0250	1.0507	1.0869	1.1368
PBr_3	1.0085	1.0259	1.0530	1.0916	1.1450
$NC_6H_5H_2$, aniline	1.0087	1.0262	1.0535	1.0925	1.1473
$SO_2(OH)Cl$	1.0091	1.0273	1.0552	1.0941	1.1465
C_2H_5Cl	1.0095	1.0285	1.0578	1.0994	1.1585
S_2Cl_2	1.0094	1.0285	1.0584	1.1016	1.1618
$CHBr_3$	1.0094	1.0287	1.0584	1.1012	——
ICl*	1.0093	1.0283	1.0586	1.1027	——
C_2H_4ICl	1.0094	1.0286	1.0587	1.1023	——
$(CH_2Br)_2$	1.0096	1.0293	1.0605	1.1061	——
$S_2O_5Cl_2$	1.0098	1.0299	1.0616	1.1074	——
CrO_2Cl_2	1.0097	1.0298	1.0618	1.1086	——
$VOCl_3$	1.0097	1.0298	1.0618	1.1087	——
$TiCl_4$	1.0099	1.0301	1.0619	1.1084	——
NC_6H_7, picoline	1.0098	1.0299	1.0620	1.1097	——
$POBrCl_2$	1.0101	1.0307	1.0630	1.1098	——
$AsCl_3$	1.0100	1.0306	1.0631	1.1104	——
$PSCl_3$	1.0102	1.0310	1.0639	1.1121	——
C_3H_5OCl, epichlorhydrin	1.0103	1.0315	1.0653	1.1155	——
C_3H_5OH, allyl alcohol	1.0103	1.0314	1.0660	1.1204	——
$P(C_2H_5O)Cl_2$ †	1.0104	1.0324	1.0680	1.1204	——
C_2Cl_3OCl	1.0110	1.0332	1.0682	1.1201	——
$CBrCl_3$	1.0109	1.0332	1.0686	1.1206	——
$POCl_3$	1.0109	1.0333	1.0693	1.1232	——
$C(NO_2)Cl_3$	1.0111	1.0337	1.0694	1.1226	——
Br_2	1.0108	1.0335	1.0698	——	——
C_2Cl_3OH	1.0111	1.0347	1.0719	——	——
$SnCl_4$	1.0117	1.0356	1.0736	1.1302	——
CH_2ClCH_2Cl	1.0116	1.0356	1.0742	——	——
CS_2	1.0116	1.0360	——	——	——
C_8H_{18} ‡	1.0119	1.0360	1.0745	1.1331	——
$SOCl_2$	1.0117	1.0360	1.0752	——	——
PCl_3	1.0117	1.0360	1.0755	——	——
C_8H_{18} §	1.0120	1.0368	1.0771	1.1401	——
CCl_4	1.0121	1.0372	1.0778	——	——
C_7H_{16} ‖	1.0122	1.0376	1.0792	1.1439	——
SO_2Cl_2	1.0124	1.0380	1.0797	——	——
C_7H_{16} ¶	1.0125	1.0386	1.0815	——	——
$CHCl_3$	1.0125	1.0387	1.0818	——	——
NC_3H_5, propionitril	1.0125	1.0388	1.0820	1.1479	——
CH_3CHCl_2	1.0130	1.0404	1.0855	——	——
CH_2Cl_2	1.0134	1.0417	——	——	——
$SiCl_4$	1.0136	1.0425	1.0904	——	——
AsF_3	1.0144	1.0433	1.0885	——	——
$CO(CH_3)_2$, acetone	1.0138	1.0433	1.0920	——	——
C_2H_3OCl	1.0139	1.0433	——	——	——
$(NO_2)_2$	1.0157	——	——	——	——

* For a body like iodine monochloride, we can assume with De Heen, that it begins to dissociate on heating already when liquid, sooner than it distils.

† $PCl_3+C_2H_5OH=HCl+P(C_2H_5O)Cl_2$

‡ Octane from methyl-hexyl-carbinol, boiling at 125°.46, sp. gr. at 0° = 0.71883.

§ Diisobutyl, boiling at 108°.5, sp. gr. at 0° = 0.71110.

‖ From *Pinus sabiniana*, boiling at 98°.4, sp. gr. at 0° = 0.70048.

¶ Ethyl-amyl, boiling at 90°.3, sp. gr. at 0° = 0.69692.

IX. Comparison of Mendelejeff's formula with the mean results of Kopp and Pierre.

(1) Wood Spirit.

t°	$V_{P,K}$	V_M	Δ	Δ^2
10	1.01176	1.01195	−19	361
20	1.02386	1.02420	−34	1156
30	1.03636	1.03675	−39	1521
40	1.04931	1.04960	−29	841
50	1.06278	1.06278	0	0
60	1.07679	1.07629	50	2500
				6379

(2) Alcohol.

t°	$V_{P,K}$	V_M	Δ	Δ^2
10	1.01059	1.01092	−33	1089
20	1.02148	1.02208	−60	3600
30	1.03275	1.03349	−74	5476
40	1.04444	1.04516	−72	5184
50	1.05661	1.05710	−49	2401
60	1.06931	1.06931	0	0
70	1.08261	1.08181	80	6400
				24150

(3) Ether.

t°	$V_{P,K}$	V_M	Δ	Δ^2
10	1.01530	1.01564	−34	1156
20	1.03137	1.03178	−41	1681
30	1.04844	1.04844	0	0
				2837

(4) Aldehyde.

t°	$V_{P,K}$	V_M	Δ	Δ^2
10	1.01680	1.01737	−57	3249
20	1.03535	1.03535	0	0
				3249

(5) Acetate of Ethyl.

t°	$V_{P,K}$	V_M	Δ	Δ^2
10	1.01293	1.01368	− 75	5625
20	1.02646	1.02742	− 96	9216
30	1.04065	1.04220	−155	24025
40	1.05562	1.05706	−144	20736
50	1.07142	1.07237	− 95	9025
60	1.08811	1.08811	0	0
70	1.10580	1.10433	147	21609
				90236

(6) Acetate of Methyl.

t°	$V_{P,K}$	V_M	Δ	Δ^2
10	1.01321	1.01372	−51	2601
20	1.02715	1.02781	−66	4356
30	1.04180	1.04231	−51	2601
40	1.05722	1.05722	0	0
50	1.07341	1.07256	85	7225
				16783

(7) Formate of Ethyl.

t°	$V_{P,K}$	V_M	Δ	Δ^2
10	1.01362	1.01381	−19	361
20	1.02767	1.02801	−34	1156
30	1.04235	1.04262	−27	729
40	1.05764	1.05764	0	0
50	1.07384	1.07310	74	5476
				7722

(8) Fusel-oil.

t°	$V_{P,K}$	V_M	Δ	Δ^2
−10	0.99066	0.99035	31	961
10	1.00932	1.00983	− 51	2601
20	1.01871	1.01987	−126	15876
30	1.02827	1.03010	−183	33489
40	1.03811	1.04054	−243	59049
50	1.04831	1.05118	−287	82369
60	1.05896	1.06205	−309	95481
70	1.07018	1.07315	−297	88209
80	1.08205	1.08448	−243	59049
90	1.09453	1.09606	−153	23409
100	1.10790	1.10790	0	0
110	1.12200	1.11998	202	40804
120	1.13720	1.13234	486	236196
130	1.15400	1.14496	904	817216
				1552709

(9) Butyrate of Methyl.

t°	$V_{P,K}$	V_M	Δ	Δ^2
10	1.01232	1.01266	− 34	1156
20	1.02494	1.02564	− 70	4900
30	1.03795	1.03896	−101	10201
40	1.05141	1.05263	−122	14884
50	1.06537	1.06667	−130	16900
60	1.07993	1.08107	−114	12996
70	1.09515	1.09588	− 73	5329
80	1.11110	1.11110	0	0
90	1.12780	1.12675	105	11025
100	1.14540	1.14284	256	65536
				142927

(10) Butyrate of Ethyl.

t°	$V_{P,K}$	V_M	Δ	Δ^2
10	1.01199	1.01246	− 47	2209
20	1.02421	1.02522	−101	10201
30	1.03677	1.03832	−155	24025
40	1.04976	1.05175	−199	39601
50	1.06327	1.06554	−227	51529
60	1.07739	1.07969	−230	52900
70	1.09224	1.09424	−200	40000
80	1.10790	1.10916	−126	15876
90	1.12450	1.12450	0	0
100	1.14200	1.14027	173	29929
110	1.16070	1.15650	420	176400
				442670

(11) Butyric Acid.

t°	$V_{P,K}$	V_M	Δ	Δ^2
10	1.01043	1.01048	− 5	25
20	1.02103	1.02118	−15	225
30	1.03183	1.03210	−27	729
40	1.04285	1.04327	−42	1764
50	1.05410	1.05468	−58	3364
60	1.06563	1.06634	−71	5041
70	1.07748	1.07826	−78	6084
80	1.08964	1.09045	−81	6561
90	1.10210	1.10292	−82	6724
100	1.11500	1.11568	−68	4624
110	1.12830	1.12873	−43	1849
120	1.14210	1.14219	0	0
130	1.15620	1.15579	41	1681
140	1.17080	1.16980	100	10000
150	1.18590	1.18417	173	29929
				78600

X. Principal Argument in terms of the Expansion for 0° Centigrade.

ϵ_0	0	1	2	3	4	5	6	7	8	9
.0000	1.0000	.9991	.9982	.9973	.9964	.9955	.9947	.9938	.9930	.9921
.0001	.9912	.9904	.9895	.9887	.9879	.9871	.9862	.9854	.9846	.9838
.0002	.9830	.9822	.9815	.9807	.9799	.9791	.9783	.9776	.9768	.9761
.0003	.9754	.9747	.9740	.9733	.9725	.9718	.9711	.9703	.9696	.9682
.0004	.9682	.9675	.9669	.9662	.9655	.9648	.9641	.9634	.9627	.9621
.0005	.9615	.9609	.9602	.9596	.9589	.9583	.9577	.9571	.9564	.9558
.0006	.9552	.9546	.9540	.9534	.9528	.9522	.9516	.9510	.9504	.9498
.0007	.9492	.9486	.9481	.9475	.9469	.9464	.9458	.9452	.9446	.9441
.0008	.9436	.9430	.9425	.9420	.9415	.9409	.9404	.9398	.9393	.9388
.0009	.9383	.9378	.9373	.9368	.9363	.9358	.9353	.9348	.9343	.9338
.0010	.9333	.9328	.9323	.9318	.9314	.9309	.9304	.9299	.9294	.9290
.0011	.9285	.9281	.9276	.9271	.9267	.9262	.9258	.9253	.9249	.9244
.0012	.9240	.9235	.9231	.9227	.9222	.9218	.9214	.9210	.9205	.9201
.0013	.9197	.9193	.9189	.9185	.9180	.9176	.9172	.9168	.9164	.9160
.0014	.9156	.9152	.9148	.9144	.9140	.9136	.9133	.9129	.9125	.9121
.0015	.9117	.9113	.9109	.9106	.9102	.9098	.9094	.9091	.9087	.9084
.0016	.9080	.9076	.9072	.9069	.9065	.9062	.9059	.9055	.9051	.9048
.0017	.9044	.9041	.9037	.9034	.9030	.9027	.9024	.9020	.9017	.9014
.0018	.9010	.9007	.9004	.9001	.8997	.8994	.8991	.8988	.8984	.8981
.0019	.8978	.8975	.8972	.8968	.8965	.8962	.8959	.8956	.8953	.8950
.0020	.8947	.8944	.8941	.8938	.8935	.8932	.8929	.8927	.8924	.8921

XI. Absolute Critical Temperature in terms of the Principal Argument.

	0	1	2	3	4	5	6	7	8	9
·90	444·7	447·7	450.8	453·9	457·1	460.4	463.8	467.2	470.7	474·4
·91	478.0	481.8	485·7	489·7	493·7	497·9	502.2	506.6	511.1	515·7
·92	520.5	525·3	530·3	535·5	540.8	546.2	551.8	557·5	563·5	569·5
·93	575.8	582.3	588.9	595.8	602.9	610.2	617.8	625.6	633.6	642.0
·94	650.6	659·5	668.7	678.3	688.2	698.5	709.2	720.3	731.8	743.8
·95	756.3	769.3	782.9	797·0	811.8	827.2	843.3	860.3	878.0	896.6
·96	916.1	936.7	958.3	981.2	1005.3	1030.8	1057.8	1084.0	1117.0	1149·5
·97	1184.1	1121.2	1260.9	1303.6	1349·5	1399·2	1453·0	1508.1	1575·4	1645·4
·98	1722.4	1807.5	1902.0	2007.8	2121.9	2261.7	2415·9	2593.8	2801.4	3046.9
·99	3341.4	3701.4	4151.5	4730.3	5502.0	6582.5	8203.4	10905.0	16308.4	32518.9

XII. mED^{-1} in terms of the Principal Argument.

		0	1	2	3	4	5	6	7	8	9
·90	$10^{11}\times$	4·526	4·649	4·776	4·907	5·042	5·182	5·327	5·477	5·633	5·794
·91		5·960	6.133	6·313	6.499	6.691	6.891	7·099	7·315	7·540	7·772
·92		8.015	8.267	8.530	8.805	9.090	9.388	9.698	10.020	10.360	10.710
·93	$10^{12}\times$	1.108	1.147	1.188	1.230	1.275	1.321	1.370	1.422	1.476	1.533
·94		1.593	1.656	1.722	1.792	1.867	1.946	2.028	2.116	2.210	2.309
·95		2.414	2.526	2.645	2.773	2.909	3.055	3.211	3.378	3.558	3.752
·96		3.960	4.186	4.430	4.695	4.982	5.296	5.638	6.013	6.424	6.876
·97		7.376	7.929	8.544	9.230	9.999	10.860	11.840	12.950	14.210	15.670
·98	$10^{13}\times$	1.735	1.931	2.161	2.433	2.758	3.151	3.633	4.232	4.987	5.960
·96		7.242	8.978	11.410	14.960	20.450	29.570	46.390	82.810	148.600	751.300

XIII. LmK^{-1} in terms of the Principal Argument and the Temperature.

Containing three significant figures.

	.90	.91	.92	.93	.94	.95	.96	.97	.98	.99
−10°	5492	6079	6822	7779	9061	10860	13560	17960	27040	54120
0°	5392	5987	6736	7696	8987	10780	13480	17900	26980	54060
10°	5288	5893	6648	7611	8910	10700	13400	17840	26910	53390
20°	5180	5796	6558	7525	8830	10630	13330	17780	26840	53920
30°	5068	5696	6466	7437	8748	10550	13260	17720	26770	53850
40°	4952	5592	6370	7347	8663	10470	13190	17660	26710	53780
50°	4828	5484	6272	7256	8579	10390	13120	17600	26640	53700
60°	4700	5372	6172	7163	8493	10320	13040	17540	26570	53630
70°	4567	5256	6068	7079	8405	10240	12970	17480	26500	53560
80°	4432	5136	5961	6983	8316	10160	12890	17410	26430	53490
90°	4293	5012	5851	6885	8226	10070	12820	17340	26360	53420
100°	4152	4882	5739	6785	8134	9990	12740	17270	26290	53340
110°	4009	4750	5625	6683	8040	9910	12660	17200	26220	53270
120°	3864	4616	5508	6578	7945	9820	12580	17130	26150	53200
130°	3726	4480	5388	6470	7849	9740	12500	17060	26080	53130
140°	3566	4342	5264	6360	7752	9650	12420	16990	26010	53050
150°	3414	4202	5139	6247	7654	9550	12330	16910	25940	52980

XIV. $(H - H')\,mK^{-1}$ in terms of the Principal Argument and the Temperature.

Containing three significant figures.

	.90	.91	.92	.93	.94	.95	.96	.97	.98	.99
−10°	9.527	8.995	8.514	8.077	7.683	7.322	6.993	6.693	6.415	6.159
0°	9.870	9.253	8.709	8.225	7.792	7.403	7.050	6.730	6.437	6.169
10°	10.253	9.539	8.919	8.383	7.904	7.485	7.108	6.766	6.460	6.176
20°	10.697	9.857	9.108	8.548	8.024	7.569	7.166	6.807	6.479	6.187
30°	11.208	10.210	9.400	8.724	8.152	7.659	7.226	6.845	6.505	6.197
40°	11.806	10.613	9.677	8.919	8.285	7.751	7.286	6.883	6.525	6.208
50°	12.525	11.065	9.977	9.128	8.424	7.850	7.351	6.925	6.548	6.218
60°	13.398	11.603	10.317	9.347	8.578	7.947	7.417	6.967	6.571	6.228
70°	14.486	12.215	10.697	9.589	8.735	8.055	7.485	7.007	6.598	6.239
80°	15.902	12.953	11.123	9.857	8.908	8.162	7.558	7.050	6.621	6.247
90°	17.752	13.837	11.612	10.147	9.088	8.276	7.627	7.094	6.645	6.257
100°	20.365	14.925	12.165	10.463	9.282	8.398	7.703	7.138	6.669	6.268
110°	24.351	16.341	12.807	10.822	9.503	8.523	7.780	7.183	6.693	6.279
120°	30.400	18.055	13.570	11.216	9.715	8.658	7.862	7.233	6.720	6.289
130°	42.543	20.421	14.472	11.658	9.956	8.797	7.943	7.279	6.745	6.299
140°	70.837	23.726	15.568	12.165	10.217	8.946	8.029	7.329	6.770	6.308
150°	269.18?	28.692	16.920	12.730	10.508	9.105	8.121	7.380	6.798	6.321

XV. $Sm^{1}D^{-1}$ in terms of the Principal Argument and Temperature.

Containing three significant figures.

	0°	10°	20°	30°	40°	50°	60°	70°
·90	300	295	289	282	276	269	262	255
·91	333	328	323	317	311	305	299	293
·92	375	370	365	360	355	349	344	338
·93	429	424	419	414	409	404	399	394
·94	500	496	491	487	482	478	473	468
·95	600	596	592	587	583	578	574	569
·96	750	746	742	738	734	730	726	722
·97	1000	996	992	988	985	981	977	974
·98	1500	1497	1495	1492	1489	1485	1481	1477
·99	3000	2997	2993	2990	2987	2983	2980	2977

	80°	90°	100°	110°	120°	130°	140°	150°
·90	247	239	231	222	215	206	198	190
·91	286	279	272	264	257	249	242	234
·92	332	326	319	313	307	300	293	286
·93	389	383	378	372	366	360	354	348
·94	463	458	453	447	442	437	432	426
·95	565	561	556	552	547	542	537	532
·96	717	713	709	705	700	696	692	687
·97	970	966	962	958	954	950	946	941
·98	1472	1468	1464	1461	1457	1454	1450	1446
·99	2973	2970	2967	2963	2960	2956	2953	2950

XVI. Variation of the Principal Argument with the Temperature.

	·90	·91	·92	·93	·94	·95	·96	·97	·98	·99
−10°	·9054	·9146	·9239	·9333	·9427	·9522	·9617	·9712	·9808	·9904
0°	·9000	·9100	·9200	·9300	·9400	·9500	·9600	·9700	·9800	·9900
10°	·8944	·9052	·9160	·9266	·9373	·9478	·9583	·9688	·9792	·9897
20°	·8884	·9002	·9118	·9232	·9345	·9456	·9566	·9675	·9785	·9893
30°	·8821	·8950	·9075	·9197	·9316	·9433	·9549	·9663	·9776	·9889
40°	·8754	·8895	·9030	·9160	·9287	·9410	·9532	·9651	·9769	·9885
50°	·8682	·8838	·8984	·9122	·9257	·9386	·9514	·9638	·9761	·9881
60°	·8605	·8776	·8935	·9084	·9226	·9363	·9496	·9625	·9753	·9877
70°	·8522	·8712	·8884	·9044	·9195	·9338	·9478	·9613	·9744	·9873
80°	·8431	·8643	·8831	·9002	·9162	·9314	·9459	·9600	·9736	·9870
90°	·8334	·8570	·8775	·8959	·9129	·9289	·9441	·9587	·9728	·9866
100°	·8227	·8492	·8717	·8915	·9095	·9263	·9422	·9574	·9720	·9862
110°	·8108	·8406	·8656	·8868	·9058	·9237	·9403	·9561	·9712	·9858
120°	·7987	·8320	·8591	·8820	·9024	·9210	·9383	·9547	·9703	·9854
130°	·7848	·8225	·8523	·8770	·8987	·9183	·9364	·9534	·9695	·9850
140°	·7709	·8124	·8451	·8717	·8949	·9155	·9344	·9520	·9687	·9847
150°	·7555	·8016	·8375	·8663	·8909	·9126	·9323	·9506	·9678	·9842

XVII. Critical Temperatures, Theoretical, Empirical and Observed.*

(Data from Thorpe and Rücker.)

	V_t	t°	$T_{1\ obs.}$	$T_{1\ em.}$	Δ	$Δ^2$	$T_{1\ th.}$	Δ	$Δ^2$
Acetate of Ethyl	1.1040 K	70	512.8 S	509.3	− 3.5	12.25	533.9	21.1	445.21
	1.1175 E	77.1	529.5 P	504.4	−25.1	630.01	532.9	3.4	11.56
Acetate of Isobutyl	1.1574 E	116.3	568.8 P	565.5	− 3.3	10.89	587.6	18.8	353.44
Acetate of Methyl	1.0733 K	50	502.8 S	503.9	+ 1.1	1.21	522.9	20.1	404.01
	1.0873 E	57.1	512.8 P	493.3	−19.5	380.25	519.1	6.3	39.69
Acetate of Propyl	1.1444 E	100.8	555.4 P	537.3	−18.1	327.61	562.9	+7.5	56.25
Acetic Acid	——	118.5	594.5 P	——	——	——	——	——	——
Acetone	1.07517 T	50	505.8 S	494.9	−10.9	118.81	503.1	−2.7	7.29
Benzene	1.1064 K	80	564.7 R	553.8	−10.9	118.81	566.5	+1.8	3.24
	1.1064 K	80	553.6 S	553.8	+ 0.2	.04	566.5	12.9	166.41
Bisulphide of Carbon	1.0489 T	40	544.8 S	566.9	+22.1	488.41	561.7	16.9	285.61
Bromide of Ethyl	1.0578 Pr	40.0	509.0 P	503.2	− 5.8	33.64	519.5	10.5	110.25
Butyrate of Ethyl	1.1692 E	119.9	577.3 P	552.2	−25.1	630.01	580.3	3.0	9.00
Butyrate of Propyl	1.1975 E	142.7	599.6 P	570.6	−29.0	841.00	600.1	0.5	.25
Chloride of Allyl	1.0675 Z	46.0	513.7 P	501.5	−12.2	148.84	520.5	6.8	46.24
Chloride of Ethyl	1.0160 Pr	10	455.6 S	455.2	− 0.4	.16	477.3	21.7	470.89

* E, Elsässer; K, Kopp; O, Oudemans; P, Pawlewski; Pr, Pierre; R, Ramsay; S, Sajotschewsky; T, Thorpe; Z, Zander.

XVII. Critical Temperatures (continued).

	V_t	t°	$T_{1\ obs.}$	$T_{1\ em.}$	Δ	$Δ^2$	$T_{1\ th.}$	Δ	$Δ^2$
Chloride of Ethylene	1.1076 T	83.5	556.0 P	567.6	+11.6	134.56	577.1	21.1	445.21
Chloride of Ethylidene	1.0854 T	59.9	527.5 P	518.4	− 9.1	82.81	536.0	8.5	72.25
Chloroform	1.08179 T	60	533.0 S	534.6	+ 1.6	2.56	546.8	13.8	190.44
[Diethylamine]	[1.0787 O	50	593.0 S	480.4	−112.6	12678.76	507.5	85.5	7310.25]
Diisobutyl	1.1553 T	108.5	543.8 P	541.4	− 2.4	5.76	575.2	31.4	985.96
Ether	1.0483 K	30	463.0 S	463.3	+ 0.3	.09	489.3	26.3	691.69
	1.0483 K	30	468.5 R	463.3	− 5.2	27.04	489.3	20.8	432.64
Formate of Ethyl	1.0735 K	50	503.0 S	502.9	− 0.1	.01	521.9	18.9	357.21
Formate of Isoamyl	1.1611 E	123.3	577.6 P	582.3	+ 4.7	22.09	600.8	23.8	566.44
Formate of Propyl	1.1180 E	81.0	540.4 P	521.5	−18.9	357.21	545.7	5.3	28.09
Propionate of Ethyl	1.1424 E	98.3	553.6 P	532.1	−21.5	462.25	558.7	5.1	26.01
Propionate of Isobutyl	1.1926 E	136.8	591.7 P	561.4	−30.3	918.09	592.4	0.7	.49
Propionate of Methyl	1.1197 E	79.9	535.7 P	511.5	−24.2	585.64	538.7	3.0	9.00
Propionate of Propyl	1.1683 E	122.2	577.8 P	562.0	−15.8	249.64	587.6	9.8	96.04
Propionic Acid	1.1781 Z	140.5	612.9 P	602.7	−10.2	104.04	617.8	4.9	24.01
Tetrachloride of Carbon	——	81.3	507.9 P	——	——	——	——	——	——
Toluene	——	109.2	593.8 P	——	——	——	——	——	——
Trichloride of Phosphorus	1.0983 T	75.9	558.5 P	561.9	+ 3.4	11.56	570.8	12.3	151.29
Total (30 observations)			——			6705.			6486.
Probable Error			7.7 ?			10.0			9.9

TABLE XVIII.

Name of Liquid.	Melting Point.	Boiling Point.	Density.	Symbol.	Principal Argument. From ϵ	From T_1	From L or E	Prob. value	References.
Acetate of Amyl		138	0.884	$C_5H_{11}OC_2H_3O$	.932			.932	VI. 56
" " Ethyl		74	0.909	$C_2H_5OC_2H_3O$	.922	.920	.935	.923	VII. 5; V.7; IX. 5; XVII.
" " Isobutyl				$(CH_3)_2C_2H_3OC_2H_3O$	.932	.929		.932	XVII.
" " Methyl		58	0.912	$CH_3OC_2H_3O$	.920	.917	.932	.921	VII. 6; V. 6; IX. 6; XVII.
" " Propyl				$C_3H_7OC_2H_3O$	.928	.927		.928	XVII.
Acetic Acid		117	1.080	HOC_2H_3O	.935	.933	.918	.933	VI. 43; XVII.
" " (anhydrous)		138	1.097	$(C_2H_3O)_2O$	.933			.933	" 41
Acetone		56	0.814	$(CH_3)_2CO$	.919	.917	.930	.920	" 72; XVII. [init.; § 5
Alcohol		78	0.812	C_2H_5OH	.932	.922	.930	.929	VII. 2; V. 2; IX. 2; § 3
Aldehyde		22	0.803	CH_3CHO	.906		*	.906	VII. 4; V. 3; IX. 4
Amyl Mercaptan		120	0.855	$C_5H_{11}SH$	.933			.933	VI. 38
Aniline		186	1.036	$C_6H_5NH_2$	.945			.945	" 8
Benzene		81	0.899	C_6H_6	.928	.927	.931	.929	" 60; XVII.
Benzoate of Amyl		261	1.004	$C_5H_{11}OC_7H_5O$	.946			.946	" 9
" " Ethyl		213	1.066	$C_2H_5OC_7H_5O$	.944			.944	" 19
" " Methyl		200	1.103	$CH_3OC_7H_5O$	.942			.942	" 16
Benzoic Acid	121	250	1.084	HOC_7H_5O	.948			.948	" 5
" Alcohol		207	1.063	C_7H_7OH	.950			.950	" 4
Bromide of Amyl		119	1.166	$C_5H_{11}Br$	.933			.933	" 42
" " Antimony	90	275	3.641	$SbBr_3$	.952			.952	" 1
" " Ethyl		41	1.473	C_2H_5Br	.920	.918		.920	" 71; XVII.

TABLE XVIII. (continued).

Name of Liquid.	Melting Point.	Boiling Point.	Density.	Symbol.	Principal Argument. From ϵ	From T_1	From L or E	Prob. value	References.
Bromide of Ethylene	20	133	2.163	$C_2H_4Br_2$	.939			.939	VI. 32
" " Methyl		13	1.664	CH_3Br	.915			.915	" 74
" " Phosphorus		175	2.925	PBr_3	.945			.945	" 13
" " Silicon		153	2.813	$SiBr_4$	.940			.940	" 25
Bromine		63	3.187	Br_2	.932		.924	.931	" 40; § 5, fin.
Butyl (?)		109	0.714	C_8H_{18}	.928			.928	" 65
Butyrate of Ethyl		117	0.903	$C_2H_5OC_4H_7O$	.928	.930		.930	VII. 10; V. 10; IX. 10; XVII.
" " Methyl		101	0.975	$CH_3OC_4H_7O$	.927		.940	.929	VII. 9; V. 9; IX. 9
" " Propyl				$C_3H_7OC_4H_8O$	.934	.934		.935	XVII.
Butyric Acid		160	0.985	HOC_4H_7O	.937		.949	.939	VII. 11; V. 8; IX. 11
Carbonate of Ethyl		126	1.000	$(C_2H_5)_2O_2CO$	.930			.930	VI. 58
Chloral		100	1.518	CCl_3CHO	.926			.926	" 26
Chloride of Acetyl		56	1.130	C_2H_3OCl	.920			.920	" 70
" " Allyl				C_3H_5Cl	.920	.919		.920	XVII.
" " Amyl		102	0.891	$C_5H_{11}Cl$	.929			.929	VI. 59
" " Antimony	73	224	2.675	$SbCl_3$	.948			.948	" 6
" " Arsenic		134	2.205	$AsCl_3$	.938		.942	.939	" 31
" " Benzoyl		198	1.232	C_7H_5OCl	.945			.945	" 14
" " Bichlorethyl		75	1.346	CH_3CCl_3	.924			.924	" 57
" " Bichlorethylene		138	1.612	$(CHCl_2)_2$	.938			.938	" 17
" " Butyl		123	1.095	C_4H_9Cl	.934			.934	" 18

TABLE XVIII. (continued).

Name of Liquid.	Melting Point.	Boiling Point.	Density.	Symbol.	Principal Argument. From ϵ	From T_1	From L or E	Prob. value	References.
Chloride of Carbon [Bi-]		79	1.630	CCl_4	.925	.917	.928	.923	VI. 61; XVII. [dene.
" " Chlorethyl		65	1.241	CH_3CHCl_2	.925			.925	" 68. See Chl. Ethyli-
" " Chlorethylene		114	1.422	$CH_2ClCHCl_2$	.934			.934	" 35
" " Ethyl		11	0.921	C_2H_5Cl	.910	.904	.903	.908	" 75; XVII.
" " Ethylene		85	1.280	$(CH_2Cl)_2$	.930	.927		.930	" 50; XVII. [ethyl.
" " Ethylidene		59	1.198	CH_3CHCl_2	.923	.921		.923	XVII. See Chl. Chlor-
" " Phosphorus		79	1.616	PCl_3	.929	.927	.924	.929	XVII.
" " Silicon		59	1.524	$SiCl_4$	.920			.920	VI. 69
" " Sulphur		144	1.706	S_2Cl_2	.940			.940	" 28
" " Tin [Bi-]		116	2.267	$SnCl_4$	.931		.936	.932	" 53
" " Titanium		136	1.761	$TiCl_4$	.937			.937	" 24
" " Trichlorethylene		154	1.663	C_2HCl_5	.940			.940	" 23
Chloroform		63	1.525	$CHCl_3$	.926	.923	.928	.926	" 49; XVII.
Cinnamate of Ethyl		267	1.066	$C_2H_5OC_9H_7O$	.948			.948	" 7
Cuminol		237	0.983	$C_{10}H_{12}O$	.946			.946	" 11
Cyanide of Methyl		72	0.835	CH_3CN	.925			.925	" 66
" " Phenyl		192	1.023	C_6H_5CN	.942			.942	" 20
Cymene		178	0.878	$C_{10}H_{14}$	.941			.941	" 22
Diethylamine		57		$(C_2H_5)_2HN$	.917	.933		.925	XVII.
Diisobutyl		109	0.711	$([CH_3]_2C_2H_3)_2$	.930	.925	*	.929	" [§ 3, init.; § 5.
Ether		35	0.736	$(C_2H_5)_2O$	.913	.906	.920	.912	VII. 3; V. 4; IX. 3; XVII.;

* Mean from the Latent Heat and the Elasticity.

TABLE XVIII. (continued).

Name of Liquid.	Melting Point.	Boiling Point.	Density.	Symbol.	Principal Argument. From ϵ	From Tl	From L or E	Prob. value	References.
Formate of Ethyl		54	0.940	C_2H_5OCHO	.920	.916	.929	.920	VII. 7; V. 5; IX. 7; XVII.
" " Isoamyl				$C_4H_8CH_3OCHO$	.934	.930		.933	XVII.
" " Methyl		33	0.998	CH_3OCHO	.917		.920	.918	VI. 73
" " Propyl				C_3H_7OCHO	.925	.924		.925	XVII.
Formic Acid		105	1.223	$HOCHO$	.937		.910	.933	VI. 34
Fusel-oil		132	0.826	$C_5H_{11}OH$	.938		.951	.940	VII. 8; V. 11; IX. 8
Iodide of Amyl		148	1.468	$C_5H_{11}I$	.937			.937	VI. 29
" " Ethyl		70	1.975	C_2H_5I	.928		.926	.928	" 55
" " Methyl		44	2.199	CH_3I	.924		.910	.922	" 64
Mustard Oil		152	1.028	C_3H_5SCN?	.936			.936	" 45
Naphthalene	79	217.	0.977	$C_{10}H_8$	.944			.944	" 3
Nitrate of Ethyl		87	1.132	$C_2H_5ONO_2$	.925			.925	" 52
Nitrobenzene		221	1.200	$C_6H_5NO_2$	.947			.947	" 10
Oil of Bitter Almonds		179	1.064	C_6H_5CHO	.944			.944	" 21
Oxalate of Ethyl		186	1.102	$(C_2H_5)_2O_2C_2O_2$	.935		.952	.938	" 46
" " Methyl	50	161	1.157	$(CH_3)_2O_2C_2O_2$	.938			.938	" 47
Phenol		189	1.081	C_6H_5OH	.948			.948	" 2
Propionate of Ethyl		98	0.923	$C_2H_5OC_3H_5O$	.925	.926		.926	" 67; XVII.
" " Isobutyl				$(CH_3)_2C_2H_3OC_3H_5O$	.933	.932		.933	XVII.
" " Methyl				$CH_3OC_3H_5O$	.924	.923		.924	"
" " Propyl				$C_3H_7OC_3H_5O$	.932	.930		.932	"

TABLE XVIII. (concluded).

Name of Liquid.	Melting Point.	Boiling Point.	Density.	Symbol.	Principal Argument. From ϵ	From T_1	From L or E	Prob. value	References.
Propionic Acid . . .		142	1.016	HOC_3H_5O	.935	.935		.936	VI. 48; XVII.
Protochloride of Carbon .		124	1.649	C_2Cl_4	.935			.935	" 30
Salicylate of Methyl . .		224	1.197	$CH_3OC_7H_5O_2$	.946			.946	" 12
Succinate of Ethyl . .		218	1.072	$(C_2H_5)_2C_4H_4O_4$	.940		*	.940	" 36
Sulphide of Carbon [Bi-] .		48·	1.293	CS_2	.928	.925	.920	.926	" 54; XVII.; § 3, init.; [§ 5.
" " Ethyl . .		91	0.837	$(C_2H_5)_2S$	.926			.926	" 63
" " Methyl [Bi-] .		113	1.064	$(CH_3)_2S_2$	.934			.934	" 37
Sulphite of Ethyl . . .		160	1.106	$(C_2H_5)_2O_2SO$	.938			.938	" 33
Sulphocyanide of Methyl .		133	1.088	CH_3SCN	.935			.935	" 27
Terebene		162	0.872	$C_{10}H_{16}$?	.940		.943	.940	" 15
Toluene		111	0.880	$C_6H_5CH_3$		.933	*	.935	XVII.
Turpentine		160	0.890	$C_{10}H_{16}$			.942	.942	§ 3, init.; § 5.
Valeraldehyde . . .		94	0.822	$(CH_3)_2C_2H_3CHO$	.925			.925	VI. 62
Valerate of Amyl . . .		189	0.879	$C_5H_{11}OC_5H_9O$	.935			.935	" 39
" " Methyl . .		116	0.902	$CH_3OC_5H_9O$	.934			.934	" 51
Valeric Acid . . .		176	0.956	HOC_5H_9O	.938		.947	.940	" 44
Water	0°	100	1.000	H_2O		.944	.948	.946	§ 3, init.; § 16, fin.
Wood Spirit . . .		66	0.817	CH_3OH	.928		.935	.929	VII. 1; V. 1; IX. 1

* Mean from the Latent Heat and the Elasticity.

PROCEEDINGS.

Seven hundred and sixty-third Meeting.

May 29, 1883. — ANNUAL MEETING.

The PRESIDENT in the chair.

The Treasurer and the Librarian presented their annual reports.

The Corresponding Secretary read the annual report of the Council.

The chairman of the Rumford Committee presented the following

REPORT OF THE RUMFORD COMMITTEE FOR THE YEAR.

Since the last report various scientific investigations have been instituted by the Committee as follows: —

I. Experiments in photographing the solar spectrum with the improved dry plates; conducted under the direction of Professor Pickering, by Mr. W. H. Pickering. The Committee have expended on this account $233.56, viz.: —

Scott's bills, $7.75 and $15	$22.75
French's bill	69.80
Clark & Sons' bill	85.00
Stevens, for labor, &c.	56.01
	$333.56

II. Experiments on the so-called Thomson effect in Thermo-electricity, and related subjects; conducted by Professor Trowbridge. The Committee have expended on this account $323, viz.: —

To Williams, for large Bunsen battery . . .	$225.00
" " for large adjusting coils . . .	98.50
	$323.50

The Committee have had under consideration, for two years, scientific work of great merit by various individuals with reference to an appropriate selection of a candidate for the Rumford Premium; and, after much deliberation, have come to a unanimous agreement to recommend to the Academy the adoption of the following votes: —

Voted, That the Rumford Premium be awarded to Professor H. A. Rowland, of Baltimore, "For his researches in Light and Heat."

Voted, That the Rumford Committee be authorized to draw upon the Treasurer of the Academy for the expenses incurred in the preparation of the gold and silver medals which constitute the Rumford Premium, and charge the same against the income of the Rumford Fund.

All of which is respectfully submitted.

JOSEPH LOVERING,
Chairman of Rumford Committee.

The report was accepted and the votes recommended were adopted.

On the motion of the Corresponding Secretary, it was

Voted, That the following should be substituted in place of No. 4 of the standing votes of the Academy: —

"One hundred extra copies of each paper published in the Memoirs or Proceedings of the Academy may be separately printed for immediate distribution, and placed at the disposal of the author free of charge; and, at the special request of the author, this number may be increased to two hundred."

The following gentlemen were elected members of the Academy: —

George Basil Dixwell, of Boston, to be a Resident Fellow in Class III., Section 3.

John William Mallet, of Charlottesville, Virginia, to be an Associate Fellow in Class I., Section 3.

Atticus Greene Haygood, of Oxford, Georgia, to be an Associate Fellow in Class III., Section 1.

Charles Adolphe Wurtz, of Paris, to be a Foreign Honorary Member in Class I. Section 3, in place of the late Friedrich Wöhler.

The annual election resulted in the choice of the following officers: —

JOSEPH LOVERING, *President.*
OLIVER W. HOLMES, *Vice-President.*
JOSIAH P. COOKE, *Corresponding Secretary.*
JOHN TROWBRIDGE, *Recording Secretary.*
HENRY P. KIDDER, *Treasurer.*
SAMUEL H. SCUDDER, *Librarian.*

Council.

EDWARD C. PICKERING,
AMOS E. DOLBEAR,
ROBERT H. RICHARDS, } of Class I.

HENRY P. BOWDITCH,
ASA GRAY,
ALEXANDER AGASSIZ, } of Class II.

EDWARD ATKINSON,
JAMES B. AMES,
JUSTIN WINSOR, } of Class III.

Rumford Committee.

WOLCOTT GIBBS, JOHN TROWBRIDGE,
EDWARD C. PICKERING, JOSIAH P. COOKE,
JOHN M. ORDWAY, JOSEPH LOVERING,
GEORGE B. CLARK.

Member of Committee of Finance.

THOMAS T. BOUVÉ.

The President appointed the following standing committees: —

Committee of Publication.

ALEXANDER AGASSIZ, JOSIAH P. COOKE,
AMOS E. DOLBEAR.

Committee on the Library.

HENRY P. BOWDITCH, WILLIAM R. NICHOLS,
HENRY W. HAYNES.

Auditing Committee.

HENRY G. DENNY, ROBERT W. HOOPER.

The following papers were presented: —

"Recent Volcanic Phenomena on the Hawaiian Islands." By William T. Brigham.

"The Flow of Lava Streams as illustrated by the Hawaiian Eruption of 1881." By William T. Brigham.

The following papers were presented by title: —

Contributions from the Chemical Laboratory of Harvard College: —

1. "On Turmerol." By C. Loring Jackson and A. E. Menke.

2. "On Curcumin." By C. Loring Jackson and A. E. Menke.

3. "On the Action of Phosphorous Trichloride on Aniline." By C. Loring Jackson and A. E. Menke.

4. "On the Action of Sodic Ethylate on Benzaldehyde." By C. Loring Jackson and G. T. Hartshorn.

5. "On the Action of Concentrated Hydrobromic Acid upon Mucobromic Acid and other Related Substances." By Henry B. Hill.

6. "On the Action of Alkaline Hydrates upon Mucobromic Acid." By Henry B. Hill and E. K. Sterns.

7. "On Phenoxychloracrylic Acid." By M. Loeb.

8. "On the Determination of Nitrites with Potassic Permanganate." By L. P. Kinnicutt and J. U. Nef.

9. "On the Determination of Sulphites with Potassic Permanganate." By L. P. Kinnicutt and R. Penrose.

"Weber's Theory of Magnetism." By John Trowbridge and C. B. Penrose.

On the motion of the Corresponding Secretary, it was

Voted, To adjourn this meeting to the second Wednesday in June.

Seven hundred and sixty-fourth Meeting.

June 13, 1883. — ADJOURNED ANNUAL MEETING.

The PRESIDENT in the chair.

The President announced the death of Gabriel Gustav Valentin, Foreign Honorary Member.

On the motion of Mr. Winsor, it was

Voted, To appropriate for the coming year, subject to the approval of a future stated meeting: —

For general expenses	$2,200.00
For publishing	2,000.00
For library	1,250.00

The following papers were presented: —

"A Method of Correcting the Weight of Bodies for the Buoyancy of the Atmosphere." By Josiah P. Cooke.

"Connection between Vision and the Kinetic Theory of Gases." By Amos E. Dolbear.

"Conversion of Camphor into Borneol." By C. Loring Jackson and A. E. Menke. (By title.)

Seven hundred and sixty-fifth Meeting.

October 10, 1883. — STATED MEETING.

The PRESIDENT in the chair.

The President announced the death of Sir Edward Sabine, of Woolwich, Foreign Honorary Member; and of Stephen Alexander, of Princeton, N. J., and William A. Norton, of New Haven, Associate Fellows.

The appropriations recommended at the adjourned annual meeting were confirmed.

The following gentlemen were elected members of the Academy: —

Arthur Michael, of Medford, to be a Resident Fellow in Class I., Section 3.

Ira Remsen, of Baltimore, to be an Associate Fellow in Class I., Section 3.

Charles Hermite, of Paris, to be a Foreign Honorary Member in Class I., Section 1, in place of the late Joseph Liouville.

The following papers were presented: —

"On Standard Time." By J. Rayner Edmands.

"On the Latitude of Harvard College Observatory, from Observations in the Prime Vertical in 1865." By William A. Rogers.

"On the Zodiacal Light." By Arthur Searle.

"The Fossil White Ants of Colorado." By Samuel H. Scudder. (By title.)

On the motion of Professor Pickering, it was

Voted, To appoint a committee, with power to consider the introduction of the system of standard time now under deliberation by the managers of railroads in the United States and Canada.

The chair appointed the following members upon this Committee: —

Messrs. Wolcott Gibbs, Francis A. Walker, and J. Rayner Edmands.

Seven hundred and sixty-sixth Meeting.

November 14, 1883. — MONTHLY MEETING.

A quorum was not present, and the Academy was not called to order.

Seven hundred and sixty-seventh Meeting.

December 12, 1883. — MONTHLY MEETING.

The PRESIDENT in the chair.

The President announced the death of John Lawrence Smith, of Louisville, and John Lawrence Le Conte, of Philadelphia, Associate Fellows; and of Oswald Heer, of Zurich, Foreign Honorary Member.

The following paper was presented: —

"On Vortex Rings studied experimentally." By Amos E. Dolbear.

Seven hundred and sixty-eighth Meeting.

January 9, 1884. — STATED MEETING.

The PRESIDENT in the chair.

The Corresponding Secretary read letters announcing the death of Joachim Barrande, of Prague, and Oswald Heer, of Zurich, Foreign Honorary Members; also a letter from Charles Hermite, acknowledging his election as Foreign Honorary Member.

The death was announced of Andrew A Humphreys, of Washington, Associate Fellow; and of Evangelinus A. Sophocles, of Cambridge, and Calvin Ellis, of Boston, Resident Fellows.

Mr. Edmands presented the following report of the committee on Standard Time.

TO THE PRESIDENT OF THE AMERICAN ACADEMY OF ARTS AND SCIENCES: —

SIR, — The Committee appointed to consider the advisability, with reference to the public convenience, of an acceptance by cities and towns of the system recently adopted by the railroads of the United States and Canada, by which the time will be uniform within each of five sections of North America, respectfully recommend the general introduction of the system for the following reasons.

It is of the greatest practical importance in a business community and among travellers to have an accepted standard time, to which well-constructed clocks and watches conform. True solar time is not regular enough for this purpose, since clocks cannot be made to keep time with it. "Mean time" is an arbitrary device which overcomes the difficulty. At different seasons of the year it is alternately faster and slower than true solar time; yet it serves practical purposes so well, that many persons are ignorant of the fact that the difference exists. As the division of the day into twenty-four hours and the calling of noon "twelve o'clock" are both mere conventional arrangements, no difficulty has been found in calling it twelve o'clock when an imaginary or "mean" sun crosses the meridian, although twice a year this mean noon varies more than a quarter of an hour from true solar noon.

For places in different longitudes, mean noon occurs at different instants. Many a suburban resident would find his watch a minute

wrong by city time should he keep it true to the local time of the town where he lives. But he fails to notice this fact because none of the clocks in his town show the local time. Suburban clocks are made to agree with those of the city, and the city clocks often show the time of some larger city. For example, there is hardly an inland city in New England which uses its own local time. Clock time, therefore, is arbitrary and conventional in nearly every respect. It is an invention which has been modified from time to time to suit practical convenience. Even in legal matters no one would think of appealing to the *true* solar time, but in the absence of statute would rely upon whatever standard is used by common consent.

The greater importance of precise time to us than to our ancestors is due to our increased facilities for dealing with those who live at a distance, — to the railroad, the telegraph, the telephone, and the fast mail. The same causes make it the more necessary to be punctual in appointments with neighbors. It is difficnlt to realize how much more important an exact knowledge of the time is for purposes of this sort than for all others. Few persons really appreciate the number and variety of interests which depend in one way or another upon the arrival and departure of trains. This is especially true of a city surrounded by well-developed suburbs. A large amount of the business of Boston, for example, is done by people who enter and leave the city daily by railroad, and the nnmber of these increases every year.

The consideration which induces a community to allow its time to differ from the local time, is the existence of a railroad which uses the time proper to some other longitude. There are no instants marked out by nature as the times for men to perform their daily recurring acts. Hours for meals vary widely; and people show the latitude which exists in the choice of times for beginning work or amusements, by taking even hours and half-hours in preference to the intermediate quarters or smaller divisions. Whatever be the standard of time, men's daily affairs can be appointed according to convenience; and, if it be desired to use even hours and half-hours by the clock, the railway standard offers as many chances for convenient arrangements as does local time. The best plan is, then, for all the time-pieces, public and private, to conform to that standard. As each railroad carries one standard to two termini, this plan is inconsistent with the general use of local time.

Heretofore there have been over fifty different standards in use at once upon the railroads of the United States and Canada. In many

places, moreover, where two or more standards are used, the local time enters to increase the confusion. Remedies for this state of things have been studied by able scientific men, discussed at length by learned societies, and developed practically by railroad managers. All purely ideal solutions have had to give way to those considerations which affect the *convenience of the public.* For example, an early suggestion was for the railroads to use one universal standard, while each community should use its own local time. But such a scheme is visionary, since neither the railroads nor the people would put it into practice. According to the plan which the railroads have recently adopted, the minute-hands of watches all over the country are to be in coincidence, but the hours are nowhere to depart far from local time; and thus the troublesome necessity of allowing for a difference of an odd number of minutes is avoided. Again, the boundaries between sections using successive hours are to be fixed with due regard to economic considerations.

Those American communities which have heretofore had their own local times must now consider whether to retain them, or submit to the temporary inconvenience of adopting the new standard, which is to come into use by the railroads. The recurring seasons of the year and the gradually altering conditions of a city often call for altering the time set to start a train, begin work, or open a public entertainment. Some inconvenience immediately results, but it is quickly compensated. If the standard of time be changed, many appointments will remain the same by the clock, with positive improvement in some cases, while others will be soon shifted according to convenience. Men will not continue long to do things too late or too early in the day just because the standard has been altered. Suppose, for example, that the clocks of a city are put back a quarter of an hour. If the time set for opening a school or factory had heretofore been thought rather early in the day, the change would be beneficial. If, on the other hand, the hour for opening had been thought rather late, the selection of a half-hour earlier by the clock would effect the same improvement. In a few weeks after the introduction of the new standard, people will be amazed to see how little is the difference it has made in matters about which anxiety is now expressed.

The introduction of uniform time will be no new experiment. In the year 1848, England, Scotland, and Wales adopted Greenwich time as a standard for the railways, the change for the western part of Scotland exceeding twenty minutes. This railway standard is now used for all ordinary purposes throughout the island. The evils which

some people feared would accompany or follow its introduction never came, and the experience of a generation with uniform time has not developed any desire to return to the system of local time.

The American case only differs from the British in the breadth of our country, which requires to be divided into several sections, whose standards differ by whole hours. Each section, however, is comparable with Great Britain. It is true that a city located upon a boundary between sections does not reap the full advantage possessed by more centrally located places, but the new system will be better than the old, even on the frontiers of the sections.

Let us trace the effect of the adoption of the new standard by the railroads upon any city which has heretofore been able to impose its local time upon the surrounding country, taking Boston as an illustration. Evidently the very causes which brought the time of the neighboring places into coincidence with that of the larger city will now carry the time of those places over to the new standard, which in this case is nearly that of Philadelphia. That is, Taunton and New Bedford, Worcester and Springfield, Fitchburg and North Adams, Lowell and Concord, Lawrence and Dover, and Portsmouth and Augusta, have heretofore used Boston time solely because their railroads did so; but when the railroads give up Boston time the bond will be broken, and Boston can only preserve the uniformity by conforming to the new standard.

Such considerations lead us to the conclusion that any city, however large, which maintains its local time after the railroads have deserted it in favor of the new standard, will isolate itself from the time of the country, and bring constantly recurring annoyance upon its citizens, its visitors, and those who deal with it by telegraph.

In order to avoid perplexities for the first few days under the new system, it is important that people throughout the country should realize that we have now the consummation of a scheme deliberately considered in all its details, and brought about by means which insure its permanence. The movement is irresistible. Officials and local boards, with which the authority may lie, should therefore take formal action in favor of it. Mills, banks, brokers' boards, and schools should announce their intention to conform to it. Lawyers and insurance companies should prepare themselves to use the slight verbal precautions which will prevent litigation arising from any uncertainty during the first few days following the change. And individuals generally should adapt their plans to the new arrangements. Already the railroads are prepared. But inaction on the part of communities leaves

room for possible misunderstandings and legal difficulties, which would be averted by a little foresight and promptness of action.

(Signed,) Wolcott Gibbs, Francis A. Walker, J. Rayner Edmands, } *Committee.*

Professor Henry P. Bowditch called the attention of the Academy to the necessity of better library accommodations; and, on his motion, it was

Voted, That a committee be appointed to consider this subject.

The chair appointed the following committee: —

Messrs. Henry P. Bowditch, Josiah P. Cooke, and Henry P. Kidder.

The following gentlemen were elected members of the Academy: —

Oliver Clinton Wendell, of Cambridge, to be a Resident Fellow in Class I., Section 2.

Joseph Thatcher Clarke, of Boston, to be a Resident Fellow in Class III., Section 2.

The following papers were presented: —

"Additional Observations confirmatory of the Relation: Imperial yard + 3.37027 inches = Metre des Archives." By William A. Rogers.

"A Possible Explanation of the Discordant Values of the Equinox determined by Pond between 1820 and 1833." By William A. Rogers.

"Observations on Variable Stars by Sir William Herschel." By Edward C. Pickering. (By title.)

Seven hundred and sixty-ninth Meeting.

February 14, 1884. — Monthly Meeting.

The President in the chair.

The Corresponding Secretary read a letter from the University of Edinburgh, inviting the Academy to send a delegate to its Tercentenary Celebration during Easter week.

The selection of a representative was left to the officers of the Academy.

The death of Arnold Guyot, of Princeton, N. J., Associate Fellow, was announced.

The special business assigned for this meeting was the presentation of the Rumford medals, which had been awarded at the annual meeting, in accordance with the recommendation of the Rumford Committee.

The President made the following address in presenting the medals to Professor Rowland: —

The medals awarded to Professor Rowland have been struck at the Philadelphia Mint, and appropriately engraved under the direction of the Rumford Committee. Their delivery to the recipient has been postponed for several meetings, under the hope and expectation that Professor Rowland would find it convenient to be present, and receive the medals in person. His attendance with us now is warmly welcomed, and adds greatly to the interest of the occasion. I ask your kind attention to a brief statement of so much of the scientific work of Professor Rowland as justifies the award of the Rumford premium, and of the relation in which these researches stand to the present condition and needs of physical science.

Astronomy, at least that part of it which relates to celestial mechanics, has presented for many generations unchallenged claims to a precision not attainable in any other science. The comparative simplicity of its problems, involving only the familiar and measurable units of mass, space, and time, has enabled it to attain and to hold this distinguished position, in spite of the fact that all the senses except vision are excluded from its study. If it has received any assistance from the experimental laws of mechanics, much more have these laws been illuminated by the motion of the planets, where friction and other resistances do not interfere.

After Grove, in 1842–43, had published his lectures on the correlation of the various physical forces; after Mayer, Helmholtz, and others had published their conclusions (the deductions partly of theory and partly of experiment) that these different forces were mutually convertible; and after the view first seized in prophetic vision by Bacon, Locke, and Winthrop was experimentally established by Rumford, Davy, Joule, and numerous coadjutors, and with ever-increasing clearness, that the assumed caloric was imaginary, and that heat was only one kind of motion in ordinary matter, —

then it was possible to introduce unity, harmony, and precision into all the physical sciences by making the familiar units of measurement universal. As other forms of energy (mechanical, electrical, magnetic, chemical, capillary, radiant, and gravitation) can be converted, directly or indirectly, into heat-energy, heat has become a universal standard of energy, current everywhere in science, and redeemable. Hence it has become of prime importance to determine the mechanical equivalent of heat, — the amount of heat, for example, which corresponds in energy to a given mass falling through a given height in a given latitude. In this way heat and all its dependencies will be measured by the units of ordinary work. For more than forty years, physicists in different countries, and by various methods, led by Joule, have been engrossed with this measurement, reaching results which have slowly but happily converged towards a common agreement.

Professor Rowland, after an historical and critical review of the methods and results of older cultivators in this rich field, has turned up the soil anew, deepening the furrows.

The fruits of his long and patient labor were made known to the Academy in 1879, in Volume XV. of the Proceedings. New apparatus was devised; the comparative merits of mercurial and air thermometers were discussed; and the various constants of science which enter into the case were re-examined. The research is a model of ingenious and conscientious experimentation, and was not published until it had received from its author the same severe criticism which he had applied to the work of others. That his final conclusion harmonizes so well with the best of Joule's, increases our confidence in both. A larger discrepancy might have given a greater show of originality; but science would have paid for the novelty by a loss of security, and another revision of the whole subject would have been entailed upon it.

When Newton announced his dynamical theory of the solar system, as simple as it was comprehensive, it made slow headway against the fanciful hypothesis of Descartes, which was intrenched in all the universities of Europe. And yet Newton's theory reposed upon a firm mathematical foundation; while that of Descartes submitted to no quantitative tests, and contradicted all the known laws of mechanics. The history of astronomy from that time almost to the present moment tells of ever new victories achieved by the combined attacks of the telescope and mathematical analysis in the province of celestial mechanics, presenting the law of gravitation as supreme

dictator to planetary and sidereal systems. But these triumphs, complete in their details, and grand in their cosmical range, were limited to questions which concern the distances, motions, dimensions, and masses of the heavenly bodies. The law of gravitation can assign a value to the quantity of matter in planets and binary stars; but it asks and can answer no question in regard to the quality of this matter, only so far as a comparison of the size and mass of a body gives a measure of its density. That an instrument would be invented or developed which would complement the mechanics of the heavens by the chemistry of planets, comets, and stars, so that a physical observatory would become a necessary adjunct of the old observatory, was beyond the hope of the most sanguine astronomer, down to the moment of its actual realization.

Newton owes his singular fame, not exclusively to his discovery and expansion of the law of gravitation, bnt partly to his experimental researches in optics. That he did not recognize the dark lines in the solar spectrum has been explained by the statement that he was obliged to use the eye of an assistant in these experiments, on account of an injury to his own. Be this as it may, the existence of these lines was first known to Wollaston in 1802; and from that moment the spectroscope and spectrum-analysis, as we now understand them, were possibilities.

Although Fraunhofer made a careful study of these lines in 1824, and Brewster, Herschel, Talbot, Draper, and many others, pursued the inquiry by way of experiment and explanation, and stood upon the threshold of a great discovery, the spectroscope and spectrum-analysis, as practical realities, date from the investigations of Kirchhoff and Bunsen, in 1862. Not only does the spectroscope carry chemistry into regions tenanted only by planets, comets, stars, and nebulæ, and reveal motions in the direction of the line of vision otherwise hopelessly beyond recognition, but it competes with the ordinary chemical analysis of bodies which can be handled, and has detected new substances which had escaped the vigilance of the chemist. Some of these results can be realized with simple instruments: others require a compound spectroscope consisting of a battery of prisms. It was a great step in the way of simplicity and ease of manipulation, when the diffraction-spectrum, produced by fine lines ruled upon glass or metal, was substituted for the spectrum produced by the combined refractions of many prisms. And here we touch upon the researches of Professor Rowland in light, which enhance his claim to the Rumford premium.

Professor Rowland's improvements in the diffraction-spectrum are manifold. 1. He has substituted for the flat plate on which the grating was formerly ruled a spherical or cylindrical surface. 2. He has ruled these lines to such a degree of fineness that 5,000, or 42,000, or even 160,000, have covered only one inch. 3. This exquisite work was executed by a machine of his own invention, and produced spectra free from the so-called ghosts which result from periodical inequalities in the ruling. 4. By making the curvature of the ruled plate discharge the office of a lens, he has avoided absorption at the violet end of the spectrum. 5. By his simple mechanical arrangements, different parts of the spectrum can be photographed with a great economy of time, and with such excellence of definition that old lines are subdivided, and new ones spring into visibility. 6. The spectrum obtained is the normal spectrum. In the words of a competent authority on the subject, "the gratings of Mr. Rowland make a new departure in spectrum-analysis." 7. Finally, his mathematical exposition of the theory of gratings has explained observed anomalies, indicated the conditions of success, and prophesied the limits at which future improvements in spectrum-analysis must stop.

Professor Rowland, it is now my duty, and certainly it is a most agreeable one, to present to you, in the name of the Academy, the gold and silver medals which constitute the Rumford premium. Count Rumford, in conveying this trust to the Academy through President John Adams, expressed a preference for such discoveries as should, in the opinion of the Academy, tend most to promote the good of mankind. The practical applications of science are numerous and valuable, and are sure of popular recognition and reward; but they often come from the most unexpected quarters. No one can predict what wonderful points of contact may be suddenly revealed between a purely theoretical investigation and the practical utilities of life. Meanwhile, a deeper insight into the laws of the material universe, extorted from a reluctant Nature only after long and patient labor and thought, and many disappointments, becomes a permanent possession for mankind; and, as long as man does not live by bread alone, it is for him a perennial blessing. The Academy, in awarding the Rumford premium to you, has indicated the kind of scientific work which, in its opinion, tends most to promote the *highest* good of mankind.

I ask you to accept, with these medals, my warm congratulations, and the cordial good wishes of all the members of the Academy here assembled to administer Count Rumford's trust.

On receiving the medals, Professor Rowland spoke as follows: —

MR. PRESIDENT, AND GENTLEMEN OF THE ACADEMY: —

I thank you for the honor you have conferred upon me, which I can but regard as the greatest honor of my life. In receiving these medals, I am pleased to think that they have been conferred upon work which is not the result of a happy accident, but of long and persistent endeavor.

There are some investigators whose disposition permits them to follow their aim, inspired by the mere love of the labor and the work. There are others to whom the sunshine of appreciation is necessary. To either class, appreciation, when it comes, is always acceptable; and I assure you that the judgment set upon my investigations by this Academy is highly valued by me.

It has been intimated that a short account of my work would be of interest to the members of the Academy. My attention was first called to the construction of dividing-engines by an inspection of a dividing-engine constructed by Professor W. A. Rogers, at Waltham, in this State. On returning to Baltimore, I devoted much time to the general problem of such machines; and, through the liberality of the trustees of the Johns Hopkins University, I was enabled to construct an engine. In about a year this engine was finished. It worked perfectly the moment it was put together, and it has not been touched since. In order to rule diffraction-gratings, I reflected that it was necessary that the screw should be perfect, and that the rests for the plate which receives the ruling should also be as perfectly adjusted as is necessary in optical experiments.

The process of making the screw consisted in grinding it in a long nut in which it was constantly reversed. When this screw was finished, there was not an error of half a wave-length, although the screw was nine inches long.

When the dividing-engine was completed, my mind was occupied with the problem of the best form of surface to receive the ruling. I speedily discovered, that, by ruling the lines on a concave mirror of long focus, I could dispense with a collimator and with the ordinary arrangement of lenses. I now rule gratings six inches long, with various numbers of lines to the inch. I find that there is no especial advantage in having more than fourteen thousand to the inch, with the ordinary conditions of ruling. Having made the concave grating, I invented a simple arrangement for mounting it, so that a photographic

camera should move along the arc of a circle at one end of a diameter, upon the other end of which the grating was placed, and always remain in focus. With this apparatus, one can do in an hour what formerly took days. Moreover, the spectra obtained are always normal spectra, and every inch on a photograph represents a certain number of wave-lengths.

After finishing my apparatus, I found it necessary to study photography; and I therefore devoted much time to this subject, and made a special study of all known emulsions. I discovered that an emulsion containing eocene enabled me to photograph from the violet down to the D line; and other emulsions were used for the red rays. I have also been engaged in enlarging my negatives, and in printing from these negatives. On these enlarged photographs, lines are doubled which have always been supposed to be single. The E line is easily doubled. My map of wave-lengths is based upon Professor Charles S. Peirce's measurements of the wave-length of a line in the green portion of the spectrum.

The following paper was presented by title: —

"Deducing from one Epoch to another Stars very near the Pole." By William A. Rogers.

Seven hundred and seventieth Meeting.

March 12, 1884. — STATED MEETING.

The PRESIDENT in the chair.

The President announced the death of Johann F. J. Schmidt, of Athens, Foreign Honorary Member; and of George Engelmann, of St. Louis, Associate Fellow.

The Corresponding Secretary read an invitation from the Royal Society of Canada to attend its third annual meeting, at Ottawa.

Professor Pickering spoke of the importance of a representation before the legislature in regard to a new topographical map of the State. The chair appointed the following committee to consider this subject: —

Messrs. Edward C. Pickering, Asa Gray, and Samuel H. Scudder.

Professor Gray spoke upon the question of a rebatement of the fees of the Academy, and the following gentlemen were appointed a committee to consider this subject: —

Messrs. Edward Atkinson, Henry P. Kidder, and Thomas T. Bouvé.

On the motion of the Corresponding Secretary, it was

Voted, That the next meeting be an adjourned stated meeting.

The following papers were presented: —

"On the Systematic Observation of Variable Stars." By Edward C. Pickering.

"On a New Magnetic Theory of Molecular Action." By Harold Whiting. (By invitation.)

Seven hundred and seventy-first Meeting.

April 9, 1884. — ADJOURNED STATED MEETING.

The PRESIDENT in the chair.

The Corresponding Secretary read letters announcing the death of Signor Quintino Sella, of Turin, President of the Reale Accademia dei Lincei, of Rome; and of Dr. George Engelmann, of St. Louis.

The following papers were presented: —

"On the Determination of the Varying Positions of Circumpolar Stars." By William A. Rogers.

"On the Phases of the Moon." By Arthur Searle.

"On the Mean Right Ascensions of One Hundred and Thirty-three Stars near the North Pole." By Truman H. Safford.

The following papers were presented by title: —

"On β-Bromtetrachlorpropionic Acid." By Charles F. Mabery.

"On α- and β-Chlordibromacrylic Acids." By Charles F. Mabery and Rachel Lloyd.

"On β-dibromdichlorpropionic and β-bromdichloracrylic Acids." By Charles F. Mabery and H. H. Nicholson.

"On Orthoiodtoluolsulphonic Acid." By Charles F. Mabery and George H. Palmer.

Seven hundred and seventy-second Meeting.

May 14, 1884. — Monthly Meeting.

The President in the chair.

The Corresponding Secretary read letters announcing the death of François Auguste Alexis Mignet, Foreign Honorary Member; also, an invitation to the twenty-fifth anniversary of the Offenbacher Verein für Naturkunde.

The Corresponding Secretary also announced that Volume XIX. of the Proceedings would be ready for distribution at the adjourned annual meeting, and that the twentieth volume had been already begun.

The President announced the death of Charles Adolphe Wurtz, Foreign Honorary Member.

The following papers were presented: —

"Systematic Errors of Magnitudes in Star Catalogues." By Edward C. Pickering.

"Recent Photographic Investigations at the Massachusetts Institute of Technology." By William H. Pickering.

The following papers were presented by title: —

"Transverse Magnetic Effects in Various Metals." By Edwin H. Hall.

"A Comparison of the Right Ascensions derived from Harvard College Observations of Maskelyne Stars during the years 1870–79 with the Fundamental Systems of Newcomb and Auwers." By William A. Rogers.

"Results of Recent Investigations conducted at the Physical Laboratory, Cambridge." By John Trowbridge.

REPORT OF THE COUNCIL.

MAY 27, 1884.

DURING the past year the Academy has lost by death eighteen members, viz.: — three Resident Fellows: Ezra Abbot, Calvin Ellis, and E. A. Sophocles; — seven Associate Fellows: Stephen Alexander, of Princeton, N. J.; J. L. Le Conte, of Philadelphia; George Engelmann, of St. Louis, Mo.; Arnold Guyot, of Princeton, N. J.; A. A. Humphreys, of Washington, D. C.; W. A. Norton, of New Haven; J. L. Smith, of Louisville; — and eight Foreign Honorary Members: Joachim Barande, of Prague; J. B. Dumas, of Paris; Oswald Heer, of Munich; F. A. A. Mignet, of Paris; Edward Sabine, of London; J. F. J. Schmidt, of Athens; Gabriel Gustav Valentin, of Berne; and Charles Adolphe Wurtz, of Paris.

RESIDENT FELLOWS.

EZRA ABBOT.

DR. ABBOT was born in Jackson, Me. He graduated at Bowdoin College in 1840. By inheritance and from his childhood of scholarly tastes and habits, he filled the years of his college life with thorough, solid work, — the fit foundation for his subsequent labor and attainments. Already imbued with the love of sacred learning, as with the devout spirit in which he ever pursued it, he was wont to take his Greek Testament into the religious meetings of the students; and, when he was the speaker, he gave to the portion of Scripture which was the theme of the hour the added light derived from the original text.

After graduation, we do not find that he had any definite career in view; and he evidently had no just appreciation of his ability to make a career for himself. He might perhaps have remained in or near his native town, and found employment in some school or academy.

But he gave himself, for its own sake and for his own sake, with an earnest singleness of purpose, to the study of the New Testament, as of the record of all that appertains to man's deepest needs and his eternal well-being. One of Professor Norton's books came into his hands, and, while he read it with vivid interest, it gave room for questions; and his was a mind that could not rest with a question unanswered. He therefore entered into communication with Mr. Norton. There is no surer index or gauge of a man's intellect than his interrogations. Only he who knows how to ask is capable of receiving. Such was Mr. Norton's belief, and he at once sought to form intimate relations with the young man who could ask so wisely. He was in feeble and declining health, and needed skilled assistance in the advancement toward completion of certain unfinished work. It was at his earnest solicitation that Mr. Abbot first came to Cambridge. Mr. Norton, in dying, left his Translation of the Gospels nearly ready for the press, but the annotations in a fragmentary and imperfect condition. The chief editorial labor in the preparation of the two volumes for the press devolved on Mr. Abbot; and the volume of Notes owes its existance to the painstaking industry and the keen critical insight with which he completed and arranged the materials expressly designed for it, but not fully elaborated, selected from the minutes taken by Mr. Norton's students in previous years such comments as had not been made obsolete by the author's maturer research and riper judgment, and filled, in accordance with the author's known opinions, such *lacunæ* as he had left unfilled. It may be doubted whether, if Mr. Norton had lived long enough to carry this volume through the press, it would have better represented his blended boldness, caution, and reverence as a critic, or have done more ample justice to his transcendent merit as an interpreter of the sacred record. Mr. Abbot afterward rendered similar, though less arduous, service in preparing for publication from imperfect manuscript a portion of Mr. Norton's intended treatise on the "Internal Evidence of the Genuineness of the Gospels."

At an early period of Mr. Abbot's residence in Cambridge he was a teacher in the public High School; and while he found there no small amount of uncongenial drudgery, he proved himself "apt to teach," and won the enduring gratitude of many willing learners. While thus engaged, he prepared a catalogue of the small library belonging to the School; and, with his life-long habit of putting the best work possible into whatever he did, he made of this little volume, not a mere list of the books, but a complete bibliographical index to their

contents. It was the first work of the kind ever done in this country; and it attracted such attention as to make an era in cataloguing, which, through him, took its place among the liberal arts. The reputation, thus accruing to him led to his appointment in 1856 as Assistant Librarian in Harvard University, with the special charge of the cataloguing department. To him is due the double system of card catalogues, in which every book is represented by a full descriptive card in the alphabetical list of authors, and by one card or more in the alphabetical list of subjects, — the subjects so covering the entire ground, and their divisions and subdivisions so distinctly marked that those who are engaged in any particular investigation can ascertain in a very brief space of time precisely what help the library can furnish. This system is extended to all important articles in periodical literature, so that whatever is to be found on the shelves is brought under the easy command of the student or inquirer. These catalogues can of course admit of the insertion of new cards without any disturbance of those previously in place. The method adapts itself to indefinite increase; and a million of books might be catalogued in rows of drawers that would occupy much less floor-room than is needed for the desks that sustain the huge, profusely interleaved, and ultimately overcrowded volumes that perform the same service for the British Museum. Mr. Abbot, as a librarian, by no means confined himself to his official duty, stringent as were its claims. He was reputed to possess such knowledge of books as no one else had; and no person engaged in any important investigation failed to resort to him for authorities and their comparative value. It was found much more satisfying and profitable to consult a living and always accessible catalogue, than to turn over cards in their cases. It was at an early period of Mr Abbot's connection with the library that he prepared the bibliographical index appended to Alger's "History of the Doctrine of a Future Life," probably the most complete list of works on eschatology ever made, and a monument of research and erudition in its kind unsurpassed, if not unequalled.

These cares and labors might have seemed sufficient for one life. But time well filled is elastic, and working hours multiply with the drafts made upon them. Mr. Abbot was all this while pursuing his Biblical studies with unbated zeal. While he was profoundly versed and skilled in hermeneutics, textual criticism became his specialty. This, of necessity, brought him into correspondence and intimate intercourse with the leading scholars in that department in this country and in Europe; and his judicial habits of mind, his entire freedom

from bias on sectarian grounds, the thoroughness of his research and comprehension, and his capacity of assigning their just value to conflicting and nearly balanced authorities have placed him for many years in the foremost rank as regards the criticism of the New Testament. In 1872, he was chosen Bussey Professor of New Testament Criticism and Interpretation in Harvard University, and immediately commenced in the Divinity School the course of instruction which thence onward was his chief life-work, pursued with unintermitted diligence through years of frequent infirmity and illness, and suspended only close under the shadow of death; though, at the last, he could not go without assistance from his carriage to his lecture-room. It is difficult to convey in words the impression which he made upon his pupils. They felt themselves in the presence of one who both had mastered his subject and was mastered by it, — whose faith had clarified his vision of Divine truth, while his clear insight had intensified his faith. His expositions were characterized by simplicity, perspicuity, positiveness of statement when he felt sure, though others might doubt, and the candid admission of doubt or ambiguity wherever he saw reason for it. In fine, his classes had the precise transcript of what he knew, what he believed, and what he felt.

It was impossible that he should not have been placed on the American Committee for the Revision of the New Testament, and no member of that board was more constant in attendance than he, or more profoundly interested in the work. How far the "readings and renderings preferred by the American Committee" were of his suggestion, we cannot say or conjecture; but there can be no doubt that, with reference to the "readings," peculiar deference was paid to his judgment. However that may have been, no one can read the list without deep regret that the American "readings and renderings" had not been adopted. With hardly an exception, they are far preferable to those that received the suffrages of the English revisers. Dr. Abbot took part in a series of meetings held by the Committee in several of our large cities, in order to interest cultivated and religious men in their work. A person who was present on one of these occasions gave us a description of the meeting. Several of the members, who were brilliant speakers, had made eloquent addresses, and the evening was far spent. When, at that late hour, Dr. Abbot rose with a paper in his hand and commenced reading with his slender thread of a voice, there was a general rustling of impatience and a turning of eyes toward the door of exit But he had hardly read his second sentence, when every eye was fixed upon him, every ear intent.

The satiety of the fully fed hearers became hunger. He closed too soon for his audience; and his address was, to all who heard him, the one event of the evening.

Dr. Abbot wrote much on the text and interpretation of the New Testament, but principally in periodicals read chiefly by Biblical scholars. Whatever he wrote was thoroughly matured; and he seems never to have published an article till he had completed, so far as his materials permitted, the study of its subject in all its relations and bearings. A collection of these articles would comprise essays on not a few of the most difficult and most warmly controverted topics of discussion as regards the text of the New Testament. Second to none of his writings is his essay on the Authorship of the Fourth Gospel, in which he demonstrates — if there can be demonstration outside of mathematics — that Justin Martyr used that Gospel, and that it can have been written by no other man than the Apostle John. In a somewhat extended range of reading on that question, we have found nothing that can be compared with this treatise as regards affluence and precision of authorities, clearness of statement, and cogency of reasoning. It is understood that Dr. Abbot had made some progress in a treatise on the internal evidence of the Johannine origin of the Fourth Gospel. We earnestly hope that this work will be found in a sufficently advanced state to be given to the public; for no man can have had a finer appreciation than he of the thick-sown tokens of the authorship of that Gospel by an eye and ear witness.

Dr. Abbot would have done more for his own reputation had he been less generous. That he gave freely of the money which was not his own self, was but a small part of his beneficence. His own mind and culture, his time and his best services, were at the command of every one who sought his aid. Some of the best work done by others in his department owes its worth, and especially its thoroughness and accuracy, to his suggestions, contributions, and revision, sometimes gratefully acknowledged in preface or foot-note, sometimes unrecognized. He did, also, all that was in his power to sustain and encourage independent labor in his chosen field. The last work of his life was to solicit funds, in addition to his own liberal benefaction, in aid of Dr. Gregory in his search for Biblical manuscripts in Eastern Europe and in Asia; and his correspondence in this behalf must have been nearly the latest, probably the very latest, letters that he wrote. But his beneficence was not confined to scholarly enterprise. For many years a Sunday-school teacher, he taught his successive classes with as painstaking care and thoroughness as if they had been pro-

fessional students, while he made them feel profoundly the inmost meaning and spirit of their Gospel lessons. No seeker for knowledge on the subjects within his range ever failed to receive all that he asked, or more. Strangers became his neighbors and kindred, when they gave him the opportunity of serving them.

Dr. Abbot was far from being a specialist in a limited sense. His scholarship was broad and large. His literary taste was singularly pure and delicate. He had, too, a keen relish for mirth, gayety, and humor; and, in his own speech and social intercourse, he illustrated the close kindred, indicated by their common family name, of wit and wisdom. He gave himself seasons of leisure and recreation too sparingly; but no one can have enjoyed such seasons more than he, or have made them more richly tributary to the enjoyment of others.

The beauty of his character was pre-eminently a "beauty of holiness." His whole soul and life were moulded, penetrated, and filled by the power and love of the Saviour, whose Gospel was his perpetual study. For those who knew him there is no need that we speak in detail of those traits of character that made him in his home and to all his friends unspeakably dear, and that leave a memory which has in it fully as much of hope as of sorrow; for there is nothing but his frail body which can be thought of as not living on in the light of heaven, and awaiting for those whom he has left the reunion to which there is no parting.

CALVIN ELLIS.

Dr. Calvin Ellis was elected a Fellow of this Academy on November 9, 1859. He never held office nor made any communication to it. His writings were chiefly medical; and they, with his high repute as Professor of Clinical Medicine in Harvard University, as a Reformer in the modes of medical instruction, and as a Physician in Boston, make him an honor to the Academy, and the Peer of any one therein.

He was born in Boston, August 15, 1826, and died on December 14, 1883. He was a lineal descendant, in the seventh generation, of a farmer named Ellis, who, with some of his fellow townsmen, emigrated to New England, in 1634, from old Dedham, county of Essex, England. They bought a large tract of land about fifteen miles from Boston, and called the town Dedham, which name it still retains. The Ellis estate has always been occupied by one of the descendants. Each generation has borne the reputation of loving and honoring work, and a desire for mental culture gradually sprang up among them. Our

associate's grandparents educated their youngest son for college. During the last two generations, this taste for mental culture has steadily grown. From the family have come some of the most eminent of our clergymen, lawyers, merchants, and men and women of intellect and character. Our associate, I believe, is the only physician who has as yet prominently appeared. Down through the race has also come free religious thought; alike removed from a superstition which cramps the mind and a science which would ignore the religious instincts of mankind.

Thus we see that our associate received amply, as a part of his hereditary constitution, three of the most precious of human qualities; namely, a belief in work, a genuine love of letters, and a religious disposition. These fine traits contributed much to the moulding of the character of Dr. Ellis, and to his career in life.

In his homestead he was most fortunate. The parents and children, loving and respecting one another, grew up together in peace. At the Chauncy Hall School, in Boston, he was fitted for Harvard University, and he entered there in 1842. He received "a part" at Commencement, which, at his especial request, was not spoken in public. Like many others, he had spent much time in sports, manly indeed, but not exactly tending to literary culture. He was an earnest member of the first Harvard Boat Club that rowed upon the Charles River.

Dr. Ellis used to say that, during his college life, he "played"; and that "he first awoke to the full meaning of life when he began the study of medicine." In 1846 he entered the Harvard Medical School. His career at that School won the entire respect of his teachers. In 1849 he became resident pupil at the Massachusetts General Hospital. While there he was found to be one of those reliable young men whose superiors were sure that any order given would be promptly and implicitly obeyed. Respectful he was to his elders, yet self-respecting all felt him to be. Of a cheerful, sunny nature, his manners to all — physicians and patients, rich and poor — were those of the true gentleman.

After receiving the degree of M. D. in 1850, he spent two years in the French and German hospitals. While there, he devoted himself much to clinical medicine, morbid anatomy, and pathology. This was of great advantage to him in his subsequent career as a medical practitioner in Boston and as Professor at the Medical School. After his return to Boston he was soon selected as assistant to Dr. J. B. S. Jackson, the eminent pathologist of that day, and one of our Fellows.

Erelong he was made Admitting Physician and Pathologist at the Massachusetts General Hospital. In 1865 he was chosen Attending Physician of the same, and held the office till his death.

Seventeen years after leaving college, in 1863, he was made Assistant Professor in the chair of the Theory and Practice of Medicine in the Harvard School. He held this office till 1865, when, at the request of the Professor of Clinical Medicine, he was chosen Adjunct Professor in that department, in which, upon the resignation of his superior in 1867, he became Professor. The Corporation of the College, in thus placing our associate in this high position, acted wisely for the institution under its charge. It is believed that the profession fully sustained that selection of one who, during the twenty years since entering upon the study of medicine, had steadily grown in the respect of all as a wise physician, an admirable teacher, and a most honorable man. At the time of his election, no one was so well qualified as he for that professorship. He held it until his death, sixteen years afterwards.

His influence on students who, year after year, passed through his curriculum, was most beneficent. From his reverence for truth, and his desire to teach them to diagnose diseases *scientifically*, he may have seemed "slow" at times to some. He did not deal in glowing assertions of his own opinions or those of others. He sought rather to develop the minds of the pupils, so that they could use them well in their subsequent lives as physicians. I learn from some of his best pupils, that, in this respect, his influence has been of immense advantage to many who are now practising their profession throughout New England. Probably this influence has been felt of late over a wider field; for, since the great improvements recently made in the administration of the Harvard Medical School, pupils have come to it from all quarters of the Union. He has been called by some a "drill-master"; and no higher compliment than this expression could be paid to any teacher, if by that "drill" he taught pupils so to grapple with the intricacies of a case that now, as physicians, they can make an accurate "diagnosis sooner and more accurately than those educated in other schools, who have not felt Dr. Ellis's power." In addition to this quality as a teacher, all the students could not help respecting him for various other excellent traits,— he was so honorable, so earnest in giving aid to all, and so kindly in his dealings with the unfortunate patients whom his class met, under his supervision, at the hospital. His example in this latter respect was a perpetual manifestation before them of all of those courtesies and kindnesses which should exist between physician and patient.

During his life as a physician, until disease checked him, he was an active participant in the exercises of the medical societies, and earnest in every good suggestion for elevating the standard of professional attainments. He was, indeed, a quiet but efficient leader amongst us.

To the local medical societies, and to the Massachusetts Medical Society, of which he was for a long time a Counsellor, he, from time to time, presented more or less elaborately prepared papers, which were subsequently published. A list of them is herewith appended. They are forty-one in number, the first having been printed in 1855, the last in 1882. He left, partly finished, a work on "Symptomatology," — still in fragments of manuscript. Some of the papers show great skill in the unravelling of the mysteries of obscure disease; and all clearly show his love of scientific accuracy, his unwillingness to lay down, as fully demonstrated, any proposition not wholly sustained by an accurate examination of every, even the most minute, fact bearing upon the subject under discussion. As clinical teacher and as a writer, instead of boldly announcing as true an opinion for which there might not be sufficient data for a perfect judgment, he was willing to remain in a state of "philosophic doubt." Let it be understood, however, that this state of doubt, as to the precise nature of a case before him, did not prevent him from being as ready promptly to prescribe for severe *symptoms*; as all other physicians are at times compelled to do — when they prescribe for *symptoms* only.

Let me refer to a few of his publications, etc.

In 1860 (No. 10 on list) he printed an essay on "Tubercle." It had gained for him the Boylston Medical Prize. After a thorough statement of the various apparently proved facts about tubercle, as given by the ablest pathologists of Europe in their various works, and from his own microscopic and other observations, he arrives at the conclusion that "tubercle" does not really exist as an entity; but that it is rather a degeneration of the existing tissues, a "want of vitality," or of a "capacity for organization." Koch had not, at that time, discovered the Bacillus.

His introductory lecture before the Medical Class in 1866 (No. 21 on list) is admirable. It teaches his hearers that the profession demands of every student the sternest loyalty to truth, abnegation and service, and, if need be, self-sacrifice. These qualities, he declares, are not too much to demand "of those who seek to interpret the laws of nature for the benefit of mankind." He refers to the many advantages derived from modern scientific methods, and to the close relation of health with disease, — the one running into the other in

their essential and minute characteristics. He claims that the "science of medicine is in advance of the art." And here he broaches the chief idea underlying his unfinished work on "Symptomatology," and declares that "to make a diagnosis needs as nice a calculation, a balancing of many points, as any legal inquiry; but instead of this we make a rough guess." "If you would elevate the profession," says he, in another part, "receive every new truth from any source." These are indeed high themes, and nobly treated by him. They are true to all the aims of this Academy in its desire that its members should strive for simple, severe truth in every branch of human learning.

In 1880 (No. 41 on list) his pamphlet on "Albuminuria as a Symptom" gives a full idea of his great learning upon that single symptom, and foreshadows more clearly the same above-named work.

This memorial would leave a meagre idea of Dr. Ellis's literary work, if we should not *attempt* to give some few details of a work upon medical diagnosis, on which for many years, and with many interruptions caused by disease, he was laboring even up to within a few days of his death. Unfortunately, it has been left in such an imperfect condition, on many and disconnected pieces of paper, which he alone could have brought together so as to make a whole production, that publication seems impossible.

The word Symptomatology was chosen by Dr. Ellis as showing somewhat the character of the work. The ideas * underlying it are, in my view, far in advance of the present mode of clinical instruction. The work would have been, in truth, an encyclopædia of all the symptoms which have been actually proved to occur in connection with the various diseases to which mankind are at times subject. These would have been arranged alphabetically, and the diseases, in which they had been thoroughly and scientifically proved to occur, would have been given. References to authors, in which the less known symptoms are reported, would have been made. This might have been called its first part. In the second part, he would have had recorded cases, for the diagnosis of which he would refer to each symptom as found in the first part. He would probably be able very soon to eliminate from any case under examination a great majority of the diseases, in which the symptom might be known to occur. In this way, he would proceed with all the symptoms recorded in the

* Dr. Ellis has distinctly declared that to Skoda and Oppolzer he owes the first conception of a plan, which he had vainly sought for from previous teachers.

case. Having gone through this course, and eliminated one disease after another, he would finally, by physical exploration, be able, not only to say what the disease is, but also, if need be, to declare what it cannot be. Dr. Ellis claimed that a thorough drilling in this way, in a method for exact diagnosis, would better prepare the pupil for future prompt performance of duty as a practitioner of medicine. For even if, perchance, the physician could not make a perfect, undoubted diagnosis in any special case, he would be better able to administer for temporary relief than one with a less drilled mind would be.

It may be a question with some, whether there ever has been anything that can be legitimately called a "scientific method," which every one could pursue in teaching clinical medicine. There have been famous "clinical teachers"; but each one has had "his own method," by which he doubtless gave much special instruction, but a method such as suggested by Dr. Ellis,* whereby knowledge, that has been *positively proved* to be true by the best experts, would be given to the pupil, and then his mind drilled in the use of all of these proved facts, in order to the perfect elucidation of a case before him, has not, I think, existed; certainly not since modern modes of scientific research have dawned upon us.

But can one hope that, with our present teachers and pupils, Dr. Ellis's plan will be immediately adopted? The teachers are unprepared for it; and many would probably sneer at it as too fatiguing for common minds, and as a very dull and "slow" method for pupils. It is to be feared that many pupils would agree to this decision. Dr. Ellis's views may well wait for a century before being duly appreciated; but that, within that time, his views, or something like them, something more accurately scientific than the present method of clinical teaching, will be demanded of clinical instructors, seems to me as certain as we are now certain that modern science, when applied to medical and surgical studies and practice, throws aside, as utterly worthless, many of the well-fought-for theories of our fathers. We can only regret that death prevented Dr. Ellis from giving to the world this matured work of his life.

These reforms have been very great during the last ten or twelve years. The Faculty, in spite of constant opposition from a small but

* In a conversation I held with Dr. Ellis only a few weeks before his death, he said to me, "I am preparing a work in which I shall give a method for clinical instruction, such as they [referring to clinical teachers] have never used before."

able minority, have carried out all their plans as "originally proposed."* These changes have made the School, in its perfect arrangements for instruction, the equal of any one in this country, and very much superior to most of them. It now vies with some of the best in Europe. By them the name of Harvard University has been greatly honored. To Dr. Ellis, as Dean of the Faculty, and his younger associates, is due the supreme merit of giving this great boon to our country.

It must be admitted that this statement contradicts the resolution accepted and recorded by the Overseers of the University at their meeting, June 22, 1882. That resolution gives the high merit of these reforms to one who was, throughout the years of discussion thereupon, their ablest opponent. Each item was carried by the Faculty, in spite of that opposition. Yet the resolution of the Overseers declares that "his [namely, the opponent's] practical wisdom and energy greatly contributed to and controlled the progressive steps by which the Medical Department of the University has reached its present high position." In other words, that resolution virtually gives to another what justly belongs to our deceased associate. Thus much the canons of biographical truthfulness require, if we would enumerate all the reasons the Academy has for honoring the memory of Dr. Ellis. These vast improvements in the means and modes of instruction in medicine, which have been, only within a very short time, finally inaugurated at the Harvard Medical School, are, of themselves, sufficient glory to any one who *has striven for them*. These reforms have been for many years intimately connected with Dr. Ellis's *life-work*. Considering their immense influence for good upon medical practice in the future of this country, they perhaps present his strongest claim to the gratitude of the medical profession and of the community, and to honor from this Academy. As all the facts mentioned in this part of our subject rest on unimpeachable authority, silence upon them, in any memorial of Dr. Ellis, would be a neglect of an obvious duty.

We have traced Dr. Ellis as a physician, a writer, a professor of medicine, and a reformer in medical education. How was he as a man, publicly and socially, in the more intimate relations of man to man? No one was ever more public-spirited than he. Twice, during the civil war, he went, at the request of the Governor of Massa-

* Words used by Dr. Ellis only a few weeks before his death, when conversing with myself on the subject. It is believed that they are true, and that medical public opinion fully sustains this assertion.

chusetts, or on appeals from others in authority, down "to the front," and sought to give aid to the wounded, to heal the sick, and to care tenderly for them. Twice he returned ill with Southern fever. The fact of his first illness did not prevent him from offering himself again a living sacrifice, if need be, in a war for his country's life and for human liberty. Of late years, when civil service reform is mooted, he has felt much interest in it. "To vote," with him, meant high duty. When comparatively well, he attended primary meetings of the citizens; and, only a few days before his death, he went from his sick-chamber to the polls, and, after depositing his vote, returned to his bed. Yet he was no politician. He thought he was acting as every honest citizen of this republic, who is not a simpleton, should act. He did his share toward upholding and purifying the government.

In his social relations no one was ever purer, no one more ready to aid a professional brother. He made no pretence to private or public charity; but his bounty was great on objects he deemed good. His large bequests to Harvard demonstrate his faith in true learning, and in Alma Mater as dispenser of it. He was liberally progressive, but never fanatical; he was too thoughtful and prudent for that. Of friends he was one of the truest type. He was most hospitable and courteous; always cheerful, and enjoyed mirth. He was never married.

He died after years of suffering, and looking forward without fear. He became partially unconscious as the end approached, and under the influence of narcotics, which, for a long time previously, he had been compelled to use, when suffering very greatly. Before this obscuring of the intellect occurred, and within a few hours of his death, he made an accurate diagnosis of the fatal symptom and its sure result, — namely, peritonitis from perforation, — and he calmly met his fate.

We can now look back upon his life with admiration. We see his strong ancestral traits. We watch his steady, never-failing growth to a wide reputation as a physician, and as one of the noblest teachers of medicine Harvard has ever had. We see him constantly cheerful and honorable, and of an indomitable energy in everything that he undertook, and in every reform for the advancement of his profession. We know that he has left throughout the country hundreds of pupils impressed with his high-toned character, and better trained physicians in consequence of his example, his teachings, and the drilling which he gave to them while under his charge.

Finally, although he never spoke to us as a body, nor gave us a written communication, has he not left to each Fellow of this Acad-

emy the precious legacy of a well-rounded life, devoted to excellence in every department in which he was called to work,—a life which, whenever it shall recur to our memory, will leave no sting, but rather stimulate us towards all that is manly and true in our social relations, and in our various branches of scientific labor?

LIST OF DR. ELLIS'S PUBLICATIONS, ETC.

No.	Year.	Title.	Where found.	Vol.	Page.
1	1855	Evidences of Arrest of Tuberculous Disease in the Lungs.	Am. J. M. S.*	29	356
2	1855	Induration of the Brain in a Child.	"	29	357
3	1855	Glandular Proliferous Cyst.	"	29	358
		Disease of the Liver.—Autopsy.	"	"	"
4	1856	Inflammation and Abscesses of the Lung, caused by Closure of the Primary Bronchus.	Bost. M. & S. J.†	55	357 380
5	1856	Case of Suicide by Antimony.	"	55	400
6	1857	Remarkable Case of Extra-uterine Fœtation, coexisting with Uterine Pregnancy.	"	56	329
7	1858	Case of Purpura simulating Rheumatism and Erysipelas.	"	59	53
8	1860	Leucocythæmia.	"	62	29
9	1860	Two Cases of Malformation.	"	62	477
10	1860	On "Tubercle." (Boylston Prize Essay.)	Am. J. M. S.	39	399
11	1861	Autopsy of a Case of Cerebral Disease without Cerebral Lesion.	Bost. M. & S. J.	64	311
12	1861	Softening of the Heart as a Cause of Sudden Death.	"	64	390
13	1861	Obstinate Vomiting terminating in Death.—Disease of Kidneys.	"	64	392
14	1861	Two Cases of Leucocythæmia, in which Crystals formed in the Blood after its Removal from the Body.	"	65	341
15	1863	Case of Addison's Disease.	"	68	361
16	1864	A Malformed Heart.	"	70	138
17	1864	Reports of Cases. Cerebro-spinal Meningitis, Typhoid Pneumonia, Disease of Heart, and Aorta; Intestinal Hemorrhage.	"	70	381
		Cerebro-spinal Meningitis. Autopsy.	"	70	404
18	1865	The Action of Causes of Depression in the Production of Structural Change; the Pathological Anatomy of Pneumonia.	"	72	229
19	1865	Congenital Tumors, containing Fœtal Structures.	"	72	417
20	1865	Spontaneous Laceration of the Aorta. Two Cases.	"	72	80

* Am. J. M. Sc.: American Journal of the Medical Sciences, Philadelphia.
† Bost. M. & S. J.: Boston Medical and Surgical Journal.

No.	Year.	Title.	Where found.	Vol.	Page.
21	1865	The Relations of Health and Disease. An Introductory Address at the Harvard Medical School. (Excellent.)	Bost. M. & S. J.	73	89
22	1866	Spontaneous Evolution in Labor. (Curious Powers of Nature.)	"	74	302
23	1867	Letter explanatory of a Criticism on No. 21.	"	76	164
24	1869	Letter from Berlin. Account of the Medical School there.	"	80	175
25	1870	The Tendency of so-called Local Diseases to Generalization.	"	83	229
26	1871	Vomiting as the Sole Prominent Symptom of Disease of the Kidneys.	"	84	425
27	1871	Autopsy of a Double Monster (Ischiopagus Tripus).	"	85	218
28	1874	On a Case of Echinococcus Cyst. (Interesting as foreshadowing his "Symptomatology.")	"	90	553
29	1874	Ovarian Cyst	"	91	182 396
30	1875	Capillary Bronchitis of Adults.	Am. Clin. Lect.*	1	No.7
31	1876	General Softening of the Brain, seldom seen as a Pathological Condition; never as a Clinical Disease.	Bost. M. & S. J.	94	29
32	1876	The Curved Line of Pleuritic Effusion.	"	95	689
33	1877	Constant Irrigation in a case of Chronic Cystitis. (Excellent suggestion and result.)	"	96	398
34	1877	The Point of Origin of the so-called "Bronchial Respiration."	"	97	1
35	1877	Ulcerative Endocarditis: Embolism of the Arteries of the Left Leg.	"	97	549
36	1878	Osteomalacia in a Man.	"	98	5
37	1879	Chest Expansion in Pleurisy.	"	100	196
38	1879	Dilated Bronchi.	"	101	162
39	1879	Probable Acute Nephritis.	"	101	696
40	1879	Effusion of Blood into the Left Hemisphere and Lateral Ventricle.	"	101	876
41	1880	The Significance of Albuminuria as a Symptom. Reprinted as a pamphlet of seventy-five pages, and a most ample account of the state of our (accurately recorded) knowledge on the subject at that time.	"	102	323 361 388 414
42	1884	"Symptomatology" (an unfinished manuscript of a proposed volume with this title). In it, Dr. Ellis intended to give a new and more scientific method of clinical instruction than has hitherto been used by Professors of Clinical Medicine.			

* Am. Clin. Lect.: A Series of American Clinical Lectures. Edited by Dr. E. C. Seguin. Vols. 1-3. New York: G. P. Putnam and Sons. 1875-77.

EVANGELINUS APOSTOLIDES SOPHOCLES.

EVANGELINUS APOSTOLIDES SOPHOCLES died, December 17, 1883, in his room in Holworthy Hall, at Harvard College. He was born in 1804 in the village of Tsangarada (Τσαγκαράδα) in Thessaly, on the slope of Mount Pelion. His father's name was Apostolos, and thus he obtained the patronymic Apostolides, which the rest of his family still continue to use as a surname. The name of Sophocles, by which he has always been known away from home, was given him in his youth by his teacher Gazes, as a compliment to his scholarship. He spent his childhood in his Thessalian home, and thus he became familiar with the scenes famous in the story of the Argonauts, with the home of Achilles, and with the rocky coast of Magnesia on which a part of the fleet of Xerxes was dashed as it was on its way to attack Greece. While still a boy he accompanied his uncle to Cairo, where he spent several years in the branch of the Sinaitic monastery of St. Catherine, visiting also the principal monastery on Mount Sinai itself. He returned to Thessaly in 1820, where he remained a year at school, chiefly studying the Greek classic authors, under the instruction of several teachers of repute, especially Anthimos Gazes, who had been twenty-five years in Vienna and had there published a periodical in Greek and a Lexicon of Ancient Greek, besides other literary works. The breaking out of the Greek Revolution in 1821 closed this school, and Sophocles, at the age of fourteen, returned to the monastery in Cairo. After a few years he left the Sinaitic brotherhood on the death of his uncle, and became again a pupil of Gazes at Syra, where he became acquainted with the Rev. Josiah Brewer, a missionary of the American Board of Foreign Missions, who visited Gazes in September, 1827. A few months later he removed with his teacher to the island of Ægina, then the seat of the Provisional Government of Greece. Mr. Brewer, who accompanied the party from Syra to Ægina, there invited Sophocles to go to the United States, and by the advice of Gazes the invitation was accepted. Sophocles arrived at Boston from Smyrna, July 15, 1828, and put himself under the tuition of Mr. Colton, of Monson, Mass. Here he studied Latin for the first time. In 1829 he entered as Freshman at Amherst College, but remained only a part of one year. He afterwards lived at Hartford and New Haven. All his earlier works were published at Hartford, where at one time he taught mathematics. In 1842 he came to Harvard College as Tutor in Greek, and remained until 1845. He

returned, in 1847, to take the same office, and since that time the college apartment in which he died, No. 2 Holworthy, has been his only home. In 1859 he was made Assistant Professor of Greek; and in 1860 a new Professorship of Ancient, Byzantine, and Modern Greek was created for him, which he continued to fill until his death. This professorship has since been abolished by vote of the Corporation and Overseers. He received the honorary degree of A. M. from Yale College in 1837, and from Harvard College in 1847; and that of LL. D. from the Western Reserve College in 1862, and from Harvard College in 1868.

The principal publications of Professor Sophocles are as follows: —

Greek Grammar, 1838; second edition (a new work), 1847.
First Lessons in Greek, 1839.
Greek Exercises, 1841; second edition, 1848.
Romaic Grammar, 1842; second edition, 1857; republished in London, 1866.
Greek Lessons for Beginners, 1843.
Catalogue of Greek Verbs, 1844.
History of the Greek Alphabet, with Remarks on Greek Orthography and Pronunciation, 1848; second edition, 1854.
Glossary of Later and Byzantine Greek, published as Vol. VII. of the Memoirs of the American Academy of Arts and Sciences, 1860.
Greek Lexicon of the Roman and Byzantine Periods (from B. C. 146 to A. D. 1100), 1870; a revised and much enlarged edition of the Glossary just mentioned.

Professor Sophocles was a scholar of extraordinary attainments. His knowledge of the Greek literature in its whole length and breadth could hardly be surpassed, and he had much rare and profound erudition on many points on which the Western scholarship is most weak. On the other hand, he treated the classic philology of Germany with neglect, if not with contempt, and he never learned German so as to read it with facility. The works of most of the great German scholars of the present century were little known to him, except so far as they were written in Latin or translated into English. But many things which are found in these works came to Sophocles independently. His native language was a great help to him in his study of Ancient Greek, and his intuitions often seemed to come to his aid where book-learning failed him. He showed little or no sympathy with the attempt to resuscitate the ancient forms of Greek in the literary language of the new kingdom of Greece; indeed, for this indifference, and for his general lack of interest in the progress of Greece since the Revolution, he was often censured by his fellow

countrymen. But much of this, as well as much of his show of indifference to the ordinary calls of humanity, was a part of his habitual cynicism, which was quite as much affected as real. While he refused to take part in most of the ordinary charities, and seldom or never let his name appear on a subscription paper, he was really in his own way one of the most benevolent of men; and it may be doubted whether there was another man in our community whose gifts bore so large a proportion to his personal expenses. Many are the poor who will miss his unostentatious benevolence now that he is gone.

Though he took little interest in any religious questions, he always remained faithful in name to the Greek Church in which he was born. In later years he renewed his relations with the monks of Mount Sinai; and as his strength failed, he wandered back more and more in his thoughts to the Sacred Mountain. The monastery of St. Catherine was enriched by more than one substantial present by his kindness, and the pious monks offered solemn prayers on Mount Sinai daily for his recovery from his last sickness, and sent him their congratulations by Atlantic cable on his saint's day. Now that he has left us, we feel that a bond is suddenly broken which connected us with a world which lies beyond our horizon. Such a phenomenon as Sophocles is indeed rare in our academic circles, and we feel that it was a privilege to have him among us.

Ἠρέμ' ὑπὲρ τύμβοιο Σοφόκλεος, ἠρέμα, κισσὲ,
Ἑρπύζοις, χλοεροὺς ἐκπροχέων πλοκάμους.

ASSOCIATE FELLOWS.

STEPHEN ALEXANDER.

Professor Stephen Alexander was born in Schenectady, N. Y., on September 1, 1806, and died at his residence in Princeton, N J., on Monday evening, June 25, 1883.

His father, who was of Scotch extraction, an active and prominent business man in Schenectady, died in 1809, at the early age of forty-four, leaving his widow with two small children, one the subject of this sketch, the other a sister, two years younger, who afterwards became the wife of Professor Henry of the Smithsonian Institution.

The property of the elder Alexander at the time of his death was considerable in amount, but to some extent in an unavailable form, consisting largely of lands scattered through the States of New York and Virginia. After the settlement of the estate his widow therefore found herself, not poor exactly, but in embarrassed circumstances, with a meagre income, and obliged to observe a careful economy.

The writer has met with no account of young Alexander's childhood and youth. Judging from his subsequent character and physique, it may be presumed that he was delicate rather than robust; not noisy, boisterous, nor fond of athletic sports, but rather quiet, gentle, and studious. He must have had good school advantages, and he must have been bright and somewhat precocious, for he completed his academic course in Union College, and graduated with high honor in 1824, before he was quite eighteen years old.

After graduation he was engaged in teaching for several years, most of the time at Chittenango, N. Y. Whether he was engaged elsewhere I have not been able to ascertain certainly, though I am disposed to think that in 1830 and 1831 he was connected with the Albany Academy. At all events his mother and family moved to Albany in 1829, where his cousin (father's sister's son), Professor Henry, was then beginning his distinguished career; and during the next two or three years they were associated together in numerous astronomical observations, as appears from letters and papers in the possession of the family. In 1830, Professor Henry married Miss Alexander, and the double relationship thus established shaped the whole life and fortune of his much loved younger cousin and brother-in-law.

In 1832, Professor Henry accepted the chair of Natural Philosophy in the College of New Jersey, and removed to Princeton with his wife and family. Professor Alexander came with them, and entered the Theological Seminary; but the next year he was appointed a Tutor in the College, a year later he was made adjunct Professor of Mathematics and in 1840 he received the chair of Astronomy. This chair he retained until 1876, though in the long period intervening the style and duties of his professorship were frequently modified. For many years he taught mathematics and astronomy, and later, giving up the mathematics, he taught natural philosophy and astronomy, but astronomy always and chiefly. In 1876, at the age of seventy, he was retired, receiving from the College, as Professor Emeritus, a suitable provision for his declining years. The remainder of his life he spent mostly at Princeton, in dignified quiet,—busy always with

mind and pen, but prevented by continually increasing feebleness from appearing much in public, or completing many things for printing.

Some months before his death he met with a singular accident, by which a shoulder was dislocated and the arm broken. Although the fracture healed and the bone knit together again, almost against expectation, yet he never regained his strength, but gradually declined and died at last, so far as appeared, from mere exhaustion.

He was married twice: first, to Miss Meads of Albany, who died in 1846, leaving three daughters, two of whom are living. His second marriage was in 1850, to Miss Forman of Princeton, who survives him, with two daughters.

His eminence was recognized in various ways during his life. In 1839, he was elected a member of the American Philosophical Society, and a fellow of our own Academy of Arts and Sciences in 1850. He received the degree of LL. D. from Columbia College in 1852; in 1859 he was President of the American Association for the Advancement of Science, and in 1862 was selected as one of the original fifty members of the National Academy of Sciences.

During his connection with the College of New Jersey he accomplished a considerable amount of valuable astronomical observation; and that, although he had no observatory nor any instrumental equipment such as would now be considered indispensable in a respectable high school. In 1835, in connection with Professor Espy, he made an accurate determination of the difference of longitude between Princeton and Philadelphia by the observation of meteors. The method had been proposed (first by Halley) more than a hundred years before; but, so far as I can learn, this was its first successful application, and the only one in this country. Not long after, similar observations were made in Germany, Ireland, and Italy. But the telegraph soon superseded shooting-stars for all such purposes. A few years later he participated with Professor Henry in thermopile observations upon the radiation of sun-spots.

But his main interest lay in the observation of solar eclipses, and in this he was enthusiastic and indefatigable. He began his astronomical career before he came to Princeton, by his observations of the annular eclipse of 1831, at Berlin, Maryland. These observations, together with certain star-occultations and calculations of the longitude of Albany, were communicated to the Albany Institute. In 1834, he went to Ebenezer, Georgia, to observe the total eclipse which occurred on November 30th of that year. Through the liberality of friends of the College, he had just come into possession of a fine

three-and-a-half-inch telescope by Fraunhofer, — an instrument which as long as he lived was his pride and his delight. It was almost amusing (and a little pathetic) to hear the old gentleman say one evening, after a magnificent view of Saturn with the twenty-three-inch telescope of the Halsted Observatory, "Yes, there is more light, but the little Fraunhofer holds its own *amazingly* well." At the time of its purchase, however, if I am not mistaken, "the little Fraunhofer" had no superior in the country except the five-inch Dollond telescope presented to Yale College about four years previously. I have never seen any account of Professor Alexander's observations of this eclipse, and am not sure that they were ever published.

In 1860, he was the astronomical chief of the large party sent out by government to observe the eclipse of that year in Labrador. The expedition was entirely successful, and its valuable results can be found in the Coast Survey Report for 1860.

In 1869, again, he was the chairman of the committee appointed by the National Academy of Sciences to organize the observation of the solar eclipse of August 7th, and himself took part in the observations at Ottumwa, Iowa. The writer's first experience in astronomical expeditions came with this eclipse, and it would be most ungrateful to leave unrecorded here the kindly courtesy with which our friend responded to my application for a place on one of the parties, and the helpful wisdom with which he assigned my work.

In 1838, 1854, 1865, and 1875, he observed the annular eclipses of those years, and, if his health had allowed, he would have gone to Denver with the Princeton party to observe the total eclipse of 1878. Several other partial eclipses and transits of Mercury, and a large number of star-occultations, were observed by him from time to time; and in December, 1882, he terminated the astronomical labor of more than fifty years by observing with great care and interest the transit of Venus.

But Professor Alexander's special forte was hardly that of an observer. As has been said, he had neither the instruments nor the opportunities for regular and consecutive observations of any kind; nor had he probably the mechanical taste and skill, or the physical strength and endurance, necessary to distinguished success in that sort of work. He was, however, very anxious to obtain the means for a careful study of the Nebulæ, for which, of course, a great telescope is indispensable. Accordingly he spared no efforts to obtain such an instrument, with a corresponding observatory. The undertaking was a difficult one, but before he retired from his professorship he saw

completed the observatory, which the generosity of his friend and admirer, General Halsted, had provided; and after weary years of waiting there came at last before his death the great instrument he had dreamed of. It was my privilege to point it for him upon some of those wonderful objects he had so long desired to see with his own eyes, and to listen to his expressions of satisfaction and delight. But the great telescope came too late for him to use it much; he labored, and others entered into his labors.

As was the case with all college professors thirty years ago, his time and strength were so occupied by the duties of instruction and discipline, in the class-room and the faculty meeting, that little remained for other work. Still he accomplished a good deal in the way of writing, as well as in observing. Though he could not be called a prolific author, yet he published in various scientific periodicals a very considerable number of papers, some of which were very elaborate, and excited no little interest and discussion. Probably the most important and characteristic of them were the four following: a paper upon "The Physical Phenomena attendant upon Solar Eclipses"; one on "The Fundamental Principles of Mathematics"; one on "The Origin of the Forms and the present Condition of the Clusters of Stars and several of the Nebulæ"; and finally, his treatise on "Certain Harmonies in the Solar System." The first of these was read at the centennial meeting of the American Philosophical Society in 1843, and a full abstract, evidently revised and corrected by the author, appears in the volume of Proceedings then published. It shows a most extensive range of reading, and is an exceedingly thorough, orderly, and exhaustive, though hardly discriminating, summary of everything that any observer ever really saw, or thought he saw, on such occasions. The paper on the Fundamental Principles of Mathematics was first read before the American Academy in 1848, and afterwards published in Silliman's Journal. It is an interesting, suggestive, and eloquent essay. The subject permitted the author to indulge his genuine Scotch love for metaphysics and hair-splitting, and he found in it also opportunity for imagination and poetry to an extent that makes the article curiously singular among mathematical disquisitions. His discussion of Nebulæ and Clusters of Stars appeared in Gould's Astronomical Journal, in a series of papers running through many numbers. The main purpose appears to be to show that many of the nebulæ and star-clusters are stars, not in the process of formation, but of disintegration, — that the nebular stage follows, in some cases, instead of preceding, the stellar.

Laplace's nebular hypothesis had a great fascination for Professor Alexander, and lay at the foundation of most of his astronomical speculations; although, as in the case just mentioned, he sometimes reached conclusions apparently much at variance with it. He was never weary of speculations bearing upon the origin and structure of the solar system, — the relations between the distances, dimensions, masses, and characteristics of the planets. His most extensive, and undoubtedly, in his own estimate, his most valuable and important work, was "The Harmonies of the Solar System," published in 1875, as one of the Smithsonian Contributions to Knowledge. In this treatise he considered that he had established the existence of certain determining ratios in the spacing of the planetary orbits, and in their satellite systems. The method, tone, and spirit of the work are essentially that of Kepler, rather than that of Galileo or Newton, and quite justifies the title of "the American Kepler" conferred upon him by a foreign critic.

Numerous other minor papers, containing observations of occultations, longitude determinations, discussions of the asteroid system, etc., are scattered through the Proceedings of the American Philosophical Society, the volumes of Silliman's Journal, Gould's Astronomical Journal, the Astronomische Nachrichten, and other scientific serials. I have not been able to form anything like a complete catalogue of them in the time at my command. The published papers of Professor Alexander are, however, very few compared with the total number of those which he presented at the meetings of the different scientific organizations to which he belonged. He was a ready and fluent speaker, easily presenting his subject from mere skeleton notes; but, like some of the rest of us, he was very impatient of the dull labor of writing necessary to prepare his matter for the press.

As a scholar Professor Alexander was unusally broad and thorough. He was an excellent linguist, familiar with Greek, Latin, and Hebrew, and well versed in the principal European languages, — at least sufficiently so to be able to read any of them except Russian with ease, and to speak and write some of them. He was fond of general literature, of history, fiction, eloquence, and poetry, and himself sometimes wrote verses of no mean order. He was a lover of metaphysics, philosophy, and theology, and delighted in controversial debate. He was familiar, of course, with the ordinary literature of his departments of instruction, with Laplace's Mécanique Celeste and many other of his mathematical writings, and with the works of Newton, Euler, and Lagrange. He always also kept up with current mathematical

and astronomical literature, to an extent unusual in his day, when foreign periodicals were expensive and hard to get.

As a teacher and lecturer, especially in his younger days, he had a remarkable power of exciting interest and enthusiasm in the subjects he dealt with. I do not think I can do better than to quote from an admirable address delivered at his funeral by Rev. Mr. Hinsdale of Princeton, an old pupil of Dr. Alexander's, and a graduate of thirty years standing, who remembers our friend as he was in the fulness of his strength and power. Having spoken of Dr. Alexander's associates in the Princeton Faculty, Dod, Torrey, J. W. and J. A. Alexander, Hope, Henry, and Guyot, Mr. Hinsdale goes on to say: —

"Of such associations Stephen Alexander was not unworthy. He pushed his researches into the depths of mathematical and astronomical science, availing himself of his acquaintance with the principal languages of Europe. He printed for the use of his students treatises on Ratio and Proportion, Differential Calculus, and Astronomy. He was unselfish in his devotion to the interests of the College, and the advancement of learning. He aroused the admiration of his pupils by the evident extent of his knowledge and his ardor in imparting it; although it must be said that he often became so profoundly interested in setting forth the philosophy of mathematics as to forget that their acquaintance with the subject was of necessity far less than his own, and so to outrun their ability to follow and comprehend him.

"The closing lectures of his course in Astronomy, in which he discussed the Nebular Hypothesis of Laplace, were characterized by a lofty and poetic eloquence, and drew to his class-room many others than the students to whom they were addressed. . . . . I vividly recall one of the occasions of which I speak; the hushed and expectant auditory; the shy, almost abashed manner of the lecturer; the rapt look, the glowing countenance, the throbbing frame, which indicated how completely he was possessed of his theme; the magnificent sweep of his ideas concerning the formation of the material universe, with its countless suns and systems; his happy application of Scripture phrase, when, pointing to the drawings of certain nebulæ of remarkable form he would quote, 'They all shall wax old as doth a garment, and as a vesture shalt thou fold them up, and they shall be changed'; the outburst of eloquence, seeming to our young minds akin to inspiration itself, with which he ascribed all the beauty and glory of creation to Him who is enthroned in majesty above all spheres, evermore controlling and guiding all, the Personal God, glorious in holiness, fearful in praises, doing wonders."

There can be no question that for many years he impressed himself profoundly upon the hundreds of young men who graduated from the College, and is remembered by them with reverence and love.

In person he was small, slight and frail, probably never weighing a hundred and twenty pounds when in his best condition. His countenance was refined, and delicate, and on occasion luminous with feeling; his manner was gentlemanly and courteous, but usually rather reserved until some interesting topic made him forget hinself, — then he was fluent and even impetuous in conversation. He was modest almost to shyness, though certainly conscious of his own real merit and ability; pure and simple-hearted as a child, and gentle unless in the presence of some wrong or meanness, — then he could blaze with unexpected fire. He was a faithful friend, a good and patriotic citizen, and an earnest and active member and officer of the church to which he belonged, always prominent in its work and counsels.

It would of course be false to say that he was faultless, but I am sure of this, — that a purer and more blameless life than his is seldom lived, and that his name will always be reverently and affectionately remembered by those who knew him best.

JOHN LAWRENCE LE CONTE.*

Dr. John Lawrence Le Conte belonged to a distinguished and wealthy family of Huguenot descent. For more than half a century the family Le Conte, father, son, and two surviving cousins, has been largely connected with the different branches of natural history of the United States. The late Dr. Le Conte was a prominent link of this respectable family pedigree.

John Lawrence Le Conte, the son of Mayor John Eaton Le Conte and Mary A. H. Lawrence, was born, May 13, 1825, in New York City. His mother died a few weeks after the birth of this child. When a boy, he was placed in St. Mary's College, Maryland, from which he graduated in 1842. His decided taste for natural history, for collecting insects, plants, or stones, developed very early, though he was never behindhand in his obligatory studies. According to the wishes of his father, his inclination for studies different from the regular course of the College was not repressed. "Once it happened

* I have, of course, used freely all the necrologies known to me; but I am personally indebted to the late Dr. J. L. Le Conte for a number of facts given here.

that, during the customary silence in the school-room, young Le Conte was seen suddenly starting from his seat and scrambling on the floor in the middle of the room. Called to the tutor's desk, he held in his hand two beetles, and explained that they were very rare, and that he could not help trying to catch them."

His progress in the study of languages and mathematics was thorough and rapid. After graduation he entered the College of Physicians and Surgeons in New York, and received his medical degree in 1846. He was in 1844, chemical assistant to Prof. John Torrey. During this time his predilection for the study of the Coleoptera of his country seems to have strongly developed, and henceforth he pursued this work through his whole life with an earnestness rarely equalled and never surpassed. He joined an entomological society, of which I believe Rev. F. J. Morris of Baltimore is the only survivor. The collections of his father, of Mr. S. S. Haldeman, of the Rev. Mr. Melsheimer and the Rev. Mr. Ziegler, were at his disposal, and before his graduation he published two papers containing the descriptions of some species believed to be new to science.

It is touching to observe how his father devoted himself to the care and development of his only child. About twenty years before, he had himself published some papers on Coleoptera, but later he took a greater interest in the previous stages of Lepidoptera. The well-known monograph, which he published together with Dr. Boisduval from Paris, France, was the fruit of these studies. But when the son decided upon the line of his studies, his father returned also to his former favorites, and published a monograph of the Histeridæ of the United States, for which the son had drawn some excellent plates. These plates evince a prominent talent for entomological drawing, and it is not easy to understand why he did not follow up this remarkable talent, (perhaps the plates for the monograph of Pasimachus are made by him,) the more so as his father was an excellent draughtsman. Mayor Le Conte was distinguished for thorough knowledge of several languages, and for his taste in fine arts and in music. So father and son studied and worked together. Once in a conversation the late Doctor spoke at some length about the works of Berosus. When I asked how it had happened that he had studied this old and rather odd author, he answered, "I have studied all such things together with my father." At this time he made his first journey to the Platte River and Fort Laramie, in 1845, after Fremont's first exploration.

A very important characteristic of his entomological publications

showed itself almost from the time when he began to work, — to be perfectly sure of the differences of the species. To obtain this aim he used dichotomical or synoptical tables, or comparative descriptions. Here, as ever afterwards, he studied as much as possible the works of other scientists, and adopted what he found available; but based his publications upon his own original studies. There exists no fairer, no better way to advance science.

It was quite natural for such an eager student to become hampered more or less seriously by the smallness of the collections within his reach, by the almost entire want of non-American insects, by the lack of sufficient literature. In his first more extensive papers he complains about these wants. But it was unknown to him, that at this time the entomological student in Europe had nowhere an advantage over the American student. Every country, with rare exceptions, was scientifically almost isolated. Only after 1849 scientific communication was opened with England, much later with Italy and America. No student of to-day can conceive the difficulties which a student had to conquer forty years ago.

For Le Conte it was decidedly fortunate that the late Dr. H. Schaum, from Berlin, Prussia, visited the United States in 1847 and 1848. Dr. Schaum, then in the prime of life, had doubtless at that time the largest knowledge of the species of Coleoptera. As nephew of Professor Germar of Halle, he had had a chance to study all the important collections in Europe. His knowledge of Micros, Pselaphidæ, and similar groups, was unsurpassed. Such a man was just what Le Conte wanted and needed, and Schaum stayed a number of weeks at his house in Philadelphia. He went with him through his whole collection, adding to it from the large collections made by himself during his journey from New Orleans to Canada, unica not excepted. I remember very well, when my friend Schaum returned to Europe, how enthusiastically he spoke about the zeal and eagerness of the gifted young student in Philadelphia. "He squeezed me dry as a lemon, and you know the extent of my knowledge of species." They became life-long friends, and their frequent correspondence was only stopped by Schaum's premature death. The impulse and advantage of this friendship is clearly to be seen in Le Conte's succeeding publications, particularly in his paper on Pselaphidæ.

The arrival of Professor L. Agassiz gave to the young student more general views, and a larger scope. He attached himself enthusiastically to the celebrated master, and formed a life-long friendship with the father, and later with the son. He accompanied Professor

Agassiz in 1849 on his exploration of Lake Superior, and published an account of the Coleoptera collected on this journey.

In the autumn of 1850 he visited California, stopping a short time at Panama, and staying in San Francisco, San José, and San Diego with Dr. C. C. Parry, who was connected with the Mexican Boundary Survey. In November he crossed the Colorado Desert, and was in February in the valley of the Gila.

In 1852, the Le Contes removed to Philadelphia. The abundant new material obtained on his journeys was directly studied. It is really marvellous to look over the large number of papers (nearly sixty) published by him in the years subsequent to his travels. Some are of great extent, as the one on Longicornia; others, called by him mostly Synopses, are shorter, but all are the result of his own most thorough study.

In 1857 Le Conte was connected for a few months with the Honduras Interoceanic Railway Survey, only to resume his interrupted scientific labor till the breaking out of the war.

In 1861, he was married to Miss Helen Grier, and after his marriage gave up the practice of medicine. Shortly after, he joined the army during the war as Lieutenant-Colonel and Medical Inspector. After the war, in 1867, he acted as geologist for the railroad survey through Kansas and New Mexico, and again in connection with his old friend, Dr. Parry.

His studies were now so far advanced, that he decided to publish a general work on the classification of the North American Coleoptera for the benefit of the increasing number of students. The first part, published in 1862, has indeed served as a basis for the study of all American students. The comparison of this work with that of Lacordaire is very interesting. Le Conte's work goes not farther than the recently published fifth volume of Lacordaire. In comparing the larger groups, the families, and the genera, it is easily understood how carefully he had studied Lacordaire's master work. But everywhere he has aimed to build up a similar work, based upon his own studies and his own convictions. This general work was followed by a new and entirely changed catalogue of the known and described species.

After such long and uninterrupted work a vacation was needed imperatively. In the autumn of 1869 he started for Europe with his family, remaining abroad until near the close of 1872, and visiting in the mean time Algiers and Egypt. As he was acknowledged in Europe as a high authority in his field, this vacation turned into more or less a working vacation. He had for the first time the chance to

see and to study extensive collections containing the insects of the whole world, and to settle many doubtful points of synonymy.

Soon after his return, he resumed his work with undaunted ardor, in connection with his pupil and friend, Dr. George H. Horn. Now began what may be called the second period of the immense work to which he had pledged his life, — the full knowledge of the Coleopterous Fauna of North America.

The first period contains his first walks in this large field. He had found indeed some good work by his predecessors; namely, by Th. Say, whose widely scattered and rare papers he collected and republished. But in general very little was finished in a manner suited to his purpose. He was obliged to go through the whole class of Coleoptera, to study everything by himself; and it has been justly said, that he presented everything in a more improved form. The work on classification and the new catalogue closed up the first period.

But during the time in which he had followed steadily his long course, a large quantity of new material had been brought to light, and nearly all new collections found their way to his laboratory. Abroad, the knowledge of Coleoptera was very much advanced, and his own views were widely enlarged. The study of the new additions necessitated a comparative study of the species known formerly. Finally, his own papers, though they had steadily advanced, needed, as he himself found, a thorough revision, in order to bring them all up to the same standard. During the first period he had published about a hundred papers, in the second period about half this number; but to these should be added the papers of Dr. Horn, and a few of the late R. Crotch (who stayed a winter in Philadelphia), as both worked on the same material, and on the same plan. It became now necessary to study the very large group of the Rhynchophora, and it has been well said by Dr. Horn, that "here Le Conte made one of the boldest strokes of his career in the isolation of that group from other Coleoptera, and by proposing a classification of them as remarkable for its novelty as it was true to nature." The species of Rhynchophora were published in 1876.

Having completed as far as possible the studies necessary for a continuation of his work on the classification of the Coleoptera, it became obvious that the advance of science during the last twenty years demanded an entirely new work. As his health was slightly failing, he associated with himself his true and most devoted friend, Dr. Horn. The new work was to be equally divided, and was begun in January,

1882. It was completed in March, 1883. It was the last effort of a life-long study.

Since 1878 he had been appointed to the United States Mint in Philadelphia. In the spring of 1883 he made his last journey to California. His health seemed to improve, then to fail again. He died on November 15, 1883, and was buried in West Laurel Hill Cemetery in Philadelphia. His wife and two sons survive him.

Le Conte's figure, his features and countenance, reminded one strongly of his French descent. Concerning his character it is sufficient to say that he had no enemy. He was an honorary member of the prominent entomological, and many other societies, as well as a member of the American Academy of Arts and Sciences. His publications will form a strong and enduring basis for all succeeding workers to build upon.*

His extensive collection was bequeathed by him to the Agassiz Museum in Cambridge. It will forever be one of the most valuable treasures of this institution.

GEORGE ENGELMANN.

In the death of Dr. Engelmann, which took place on the 4th of February last, the American Academy has lost one of its very few Associate Fellows in the Botanical Section, and the science one of its most eminent and venerable cultivators.

He was born at Frankfort-on-the-Main, February 2, 1809, and had therefore just completed his seventy-fifth year. His father, a younger member of the family of Engelmanns who for several generations served as clergymen at Bacharach on the Rhine, was also educated for the ministry, and was a graduate of the University of Halle, but he devoted his life to education. Marrying the daughter of George Oswald May, a somewhat distinguished portrait-painter, they established at Frankfort, and carried on for a time with much success, a school for young ladies, such as are common in the United States, but were then a novelty in Germany.

George Engelmann was the eldest of thirteen children born of this marriage, nine of whom survived to manhood. Assisted by a scholarship founded by "the Reformed Congregation of Frankfort," he went

* Mr. S. Henshaw has published a "List of Le Conte's Entomological Writings," Cambridge, 1878, 4to; and an Index to the Coleoptera described by Le Conte, in Trans. Amer. Entom. Soc., 1881, vol. ix.

to the University of Heidelberg in the year 1827, where he had as fellow students and companions Karl Schimper and Alexander Braun. With the latter he maintained an intimate friendship and correspondence, interrupted only by the death of Braun in 1877. The former, who manifested unusual genius as a philosophical naturalist, after laying the foundations of phyllotaxy, to be built upon by Braun and others, abandoned, through some singular infirmity of temper, an opening scientific career of the highest promise, upon which the three young friends, Agassiz, Braun, and Schimper, and in his turn Engelmann, had zealously entered.

Embarrassed by some troubles growing out of a political demonstration by the students at Heidelberg, Engelmann in the autumn of 1828 went to Berlin University for two years; and thence to Wurzburg, where he took his degree of Doctor in Medicine in the summer of 1831. His inaugural dissertation, *De Antholysi Prodromus*, which he published at Frankfort in 1832, testifies to his early predilection for Botany, and to his truly scientific turn of mind. It is a morphological dissertation, founded chiefly on the study of monstrosities, illustrated by five plates filled with his own drawings. It was therefore quite in the line with the little treatise on the Metamorphosis of Plants, published forty years before by another and the most distinguished native of Frankfort, and it appeared so opportunely that it had the honor of Goethe's notice and approval. Goethe's correspondent, Madame von Willema, sent a copy to him only four weeks before his death. Goethe responded, making kind inquiries after young Engelmann, who, he said, had completely apprehended his ideas of vegetable morphology, and had shown such genius in their development that he offered to place in this young botanist's hands the store of unpublished notes and sketches which he had accumulated.

The spring and summer of 1832 were passed at Paris in medical and scientific studies, with Braun and Agassiz as companions, leading, as he records, "a glorious life in scientific union, in spite of the cholera.' Meanwhile, Dr. Engelmann's uncles had resolved to make some land investments in the valley of the Mississippi, and he willingly became their agent. At least one of the family was already settled in Illinois, not far from St. Louis. Dr. Engelmann, sailing from Bremen for Baltimore in September, joined his relatives in the course of the winter, made many lonely and somewhat adventurous journeys on horseback in Southern Illinois, Missouri, and Arkansas, which yielded no other fruits than those of botanical exploration; and finally he established himself in the practice of medicine at St. Louis, late in the

autumn of 1835. St. Louis was then rather a frontier trading-post than a town, of barely eight or ten thousand inhabitants. He lived to see it become a metropolis of over four hundred thousand. He began in absolute poverty, the small means he had brought from Europe completely exhausted. In four years he had laid the foundations of success in his profession, and had earned the means for making a voyage to Germany, and, fulfilling a long-standing engagement, for bringing to a frugal home the chosen companion of his life, Dora Hartsmann, his cousin, whom he married at Kreuznach, on the 11th of June, 1840. On his way homeward, at New York, the writer of this memorial formed the personal acquaintance of Dr. Engelmann; and thus began the friendship and the scientific association which has continued unbroken for almost half a century.

Dr. Engelmann's position as a leading physician in St. Louis, as well among the American as the German and French population, was now soon established. He was even able in 1856, without risk, to leave his practice for two years, to devote most of the first summer to botanical investigation in Cambridge, and then, with his wife and young son, to revisit their native land, and to fill up a prolonged vacation in interesting travel and study. In the year 1868 the family visited Europe for a year, the son remaining to pursue his medical studies in Berlin. And lastly, his companion of nearly forty years having been removed by death in January, 1879, and his own robust health having suffered serious and indeed alarming deterioration, he sailed again for Germany in the summer of 1883. The voyage was so beneficial that he was able to take up some botanical investigations, which, however, were soon interrupted by serious symptoms. But the return voyage proved wonderfully restorative; and when, in early autumn, he rejoined his friends here, they could hope that the unfinished scientific labors, which he at once resumed with alacrity of spirit, might still for a while be carried on with comfort. So indeed they were, in some measure, after his return to his home, yet with increasing infirmity and no little suffering until the sudden illness supervened which, in a few days, brought his honorable and well-filled life to a close.

In the latter part of his life Dr. Engelmann was able to explore considerable portions of his adopted country, the mountains of North Carolina and Tennessee, the Lake Superior region, and the Rocky Mountains and contiguous plains in Colorado and adjacent territories, and so to study in place, and with the particularity which characterized his work, the *Cacti*, the *Coniferæ*, and other groups of plants

which he had for many years been specially investigating. "In 1880 he made a long journey through the forests of the Pacific States, where he saw for the first time in the state of nature plants which he had studied and described more than thirty years before. Dr. Engelmann's associates [so one of them declares] will never forget his courage and industry, his enthusiasm and zeal, his abounding good-nature, and his kindness and consideration of every one with whom he came in contact." His associates, and also all his published writings, may testify to his acuteness in observation, his indomitable perseverance in investigation, his critical judgment, and a rare openness of mind which prompted him continually to revise old conclusions in the light of new facts or ideas.

In the consideration of Dr. Engelmann's botanical work, — to which these lines will naturally be devoted, — it should be remembered that his life was that of an eminent and trusted physician, in large and general practice, who even in age and failing health was unable — however he would have chosen — to refuse professional services to those who claimed them; that he devoted only the residual hours, which most men use for rest or recreation, to scientific pursuits, mainly to botany, yet not exclusively. He was much occupied with meteorology. On establishing his home at St. Louis, he began a series of thermometrical and barometrical observations, which he continued regularly and systematically to the last, when at home always taking the observations himself, — the indoor ones even up to the last day but one of his life. Even in the last week he was seen sweeping a path through the snow in his garden to reach his maximum and minimum thermometers. His latest publication (issued since his death by the St. Louis Academy of Sciences) is a digest and full representation of the thermometrical part of these observations for forty-seven years. He apologizes for not waiting the completion of the half-century before summing up the results, and shows that these could not after three more years be appreciably different.

A list of Dr. Engelmann's botanical papers and notes, collected by his friend and associate, Professor Sargent, and published in Coulter's Botanical Gazette for May, 1884, contains about one hundred entries, and is certainly not quite complete. His earliest publication, his inaugural thesis already mentioned (*De Antholysi Prodromus*), is a treatise upon teratology in its relations to morphology. It is a remarkable production for the time and for a mere medical student with botanical predilections. There is an interesting recent analysis of it in "Nature," for April 24, by Dr. Masters, the leading teratologist of our

day, who compares it with Moquin-Tandon's more elaborate *Tératologie Végétale*, published ten years afterwards, and who declares that, "when we compare the two works from a philosophical point of view, and consider that the one was a mere college essay, while the other was the work of a professed botanist, we must admit that Engelmann's treatise, so far as it goes, affords evidence of deeper insight into the nature and causes of the deviations from the ordinary conformation of plants than does that of Moquin."

Transferred to the valley of the Mississippi and surrounded by plants most of which still needed critical examination, Dr. Engelmann's avocation in botany and his mode of work were marked out for him. Nothing escaped his attention; he drew with facility; and he methodically secured his observations by notes and sketches, available for his own after use and for that of his correspondents. But the lasting impression which he has made upon North American botany is due to his wise habit of studying his subjects in their systematic relations, and of devoting himself to a particular genus or group of plants (generally the more difficult) until he had elucidated it as completely as lay within his power. In this way all his work was made to tell effectively.

Thus his first monograph was of the genus *Cuscuta* (published in the American Journal of Science, in 1842), of which when Engelmann took it up we were supposed to have only one indigenous species, and that not peculiar to the United States, but which he immediately brought up to fourteen species without going west of the Mississippi valley. In the year 1859, after an investigation of the whole genus in the materials scattered through the principal herbaria of Europe and this country, he published in the first volume of the St. Louis Academy of Sciences a systematic arrangement of all the Cuscutæ, characterizing seventy-seven species, besides others classed as perhaps varieties.

Mentioning here only monographical subjects, we should next refer to his investigations of the Cactus family, upon which his work was most extensive and important, as well as particularly difficult, and upon which Dr. Engelmann's authority is of the very highest. He essentially for the first time established the arrangement of these plants upon floral and carpological characters. This formidable work was begun in his sketch of the Botany of Dr. A. Wislizenus's Expedition from Missouri to Northern Mexico, in the latter's memoir of this tour, published by the United States Senate. It was followed up by his account (in the American Journal of Science, 1852) of the Giant Cactus

on the Gila (*Cereus giganteus*) and an allied species; by his synopsis of the Cactaceæ of the United States, published in the Proceedings of the American Academy of Arts and Sciences, 1856; and by his two illustrated memoirs upon the Southern and Western species, one contributed to the fourth volume of the series of Pacific Railroad Expedition Reports, the other to Emory's Report on the Mexican Boundary Survey. He had made large preparations for a greatly needed revision of at least the North American *Cactaceæ*. But, although his collections and sketches will be indispensable to the future monographer, very much knowledge of this difficult group of plants is lost by his death.

Upon two other peculiarly American groups of plants, very difficult of elucidation in herbarium specimens, *Yucca* and *Agave*, Dr. Engelmann may be said to have brought his work up to the time. Nothing of importance is yet to be added to what he modestly styles "Notes on the Genus *Yucca*," published in the third volume of the Transactions of the St. Louis Academy, 1873, and not much to the "Notes on *Agave*," illustrated by photographs, included in the same volume and published in 1875.

Less difficult as respects the material to work upon, but well adapted for his painstaking, precise, and thorough handling, were such genera as *Juncus* (elaborately monographed in the second volume of the Transactions of the St. Louis Academy, and also exemplified in distributed sets of specimens), *Euphorbia* (in the fourth volume of the Pacific Railroad Reports, and in the Botany of the Mexican Boundary), *Sagittaria* and its allies, *Callitriche*, *Isoetes* (of which his final revision is probably ready for publication), and the North American *Loranthaceæ*, to which *Sparganium*, certain groups of *Gentiana*, and some other genera, would have to be added in any complete enumeration. Revisions of these genera were also kindly contributed to Dr. Gray's Manual; and he was an important collaborator in several of the memoirs of his surviving associate and friend.

Of the highest interest, and among the best specimens of Dr. Engelmann's botanical work, are his various papers upon the American Oaks and the *Coniferæ*, published in the Transactions of the St. Louis Academy and elsewhere, the results of long-continued and most conscientious study. The same must be said of his persevering study of the North American Vines, of which he at length recognized and characterized a dozen species, — excellent subjects for his nice discrimination, and now becoming of no small importance to grape-growers, both in this country and in Europe. Nearly all that we

know scientifically of our species and forms of *Vitis* is directly due to Dr. Engelmann's investigations. His first separate publication upon them, "The Grape Vines of Missouri," was published in 1860; his last, a re-elaboration of the American species, with figures of their seeds, is in the third edition of the Bushberg Catalogue, published only a few months ago.

Imperfect as this mere sketch of Dr. Engelmann's botanical authorship must needs be, it may show how much may be done for science in a busy physician's *horæ subsecivæ*, and in his occasional vacations. Not very many of those who could devote their whole time to botany have accomplished as much. It need not be said, and yet perhaps it should not pass unrecorded, that Dr. Engelmann was appreciated by his fellow botanists both at home and abroad, that his name is upon the rolls of most of the societies devoted to the investigation of nature, that he was "everywhere the recognized authority in those departments of his favorite science which had most interested him," and that, personally one of the most affable and kindly of men, he was as much beloved as respected by those who knew him.

More than fifty years ago his oldest associates in this country — one of them his survivor — dedicated to him a monotypical genus of plants, a native of the plains over whose borders the young immigrant on his arrival wandered solitary and disheartened. Since then the name of Engelmann has, by his own researches and authorship, become unalterably associated with the Buffalo-grass of the plains, the noblest Conifers of the Rocky Mountains, the most stately Cactus in the world and with most of the associated species, as well as with many other plants of which perhaps only the annals of botany may take account. It has been well said by a congenial biographer, that "the Western plains will still be bright with the yellow rays of *Engelmannia*, and that the splendid Spruce, the fairest of them all, which bears the name of Engelmann, will still, it is to be hoped, cover with noble forests the highest slopes of the Rocky Mountains, recalling to men, as long as the study of trees occupies their thoughts, the memory of a pure, upright, and laborious life."

ARNOLD GUYOT.

Arnold Guyot, Ph.D., LL. D., was born near Neufchâtel, Switzerland, September 28, 1807. His earlier studies were pursued at Neufchâtel, Stuttgart, and Carlsruhe. In his delightful memoir of his friend Agassiz, prepared for the National Academy, he gives a beau-

tiful picture of his first scientific studies. He subsequently studied theology for three years at Neufchâtel and Berlin, at the latter place attending the lectures of Neander, Hengstenberg, and Schleiermacher. His interest in scientific studies was increased by the Professors with whom he now came in contact, and the peculiar opportunities he enjoyed. Unwilling to enter upon the high duties of the Christian ministry with a divided mind, he turned aside from his theological course and devoted himself to science, a field more congenial to his taste, and, as he conscientiously believed, better adapted to his capacities.

He passed five years in Berlin in scientific study, attending the lectures upon physics, chemistry, meteorology, geology, mineralogy, physical geography, botany, and zoölogy, from such men as Dove, Erman, Mitscherlich, Weiss, Hoffman, Lichtenstein, Steffens, Ritter, and others. Portraits of Ritter, Steffens, and Humboldt he always kept upon the walls of his study, in memory of his student days. Upon the especial recommendation of Humboldt, he was granted free access to the Royal Botanical Gardens, and the chief gardener furnished him weekly with hundreds of cut specimens of the rarest exotics for his herbarium. To Steffens he owed much in philosophy, and a letter of Ritter, which was unfortunately lost some years since, bore testimony, not merely to the ability of the young student, but to the scientific position and attainments of the physical geographer who was second in this department of science only to Ritter himself. In 1835, Mr. Guyot received his degree of Ph.D. from the University of Berlin. He had spent five years in the family of Herr Müller, the Privy Councillor of King Frederick William III. He now removed to Paris and became the private instructor of the young sons of Count de Pourtales. By special arrangement, however, he continued his scientific studies, and also devoted himself to history, under Michelet. His summers were spent in scientific excursions in France, Belgium, Holland, Italy, and Switzerland.

As early as 1838 he discovered, and announced in a paper read before the Geological Society of France, most of the important laws concerning the formation, nature, and motion of the glaciers. He first discovered the laminated structure of the ice, and explained the blue and white bands; showed that the motion of the glacier is due to the displacement of its molecules, which constitute its plasticity and explain its moulding, &c. These discoveries were subsequently illustrated and confirmed by the investigations of Agassiz and Forbes; while he, with characteristic modesty, remained silent, and did not even publish his paper until 1883. In 1839, Mr. Guyot was ap-

pointed Professor of History and Physical Geography in the Academy of Neufchâtel, which was now upon a university basis. Agassiz was among his colleagues at this time. Here he delivered no less than thirteen different courses of lectures in connection with the two departments of which he had charge. Agassiz having taken up the glaciers with his usual enthusiasm, Professor Guyot entered upon an investigation of the erratic bowlders, which had been neglected since the last observations of De Charpentier. During seven successive summers Professor Guyot conducted his investigations on both sides of the Central Alps in Switzerland and in Italy. From eleven different basins, covering a surface three hundred miles long and two hundred miles wide, he collected about six thousand specimens of rocks as vouchers of the results. One set of these specimens he placed in the museum at Neufchâtel; the other, he gave to the Museum of the College of New Jersey. From these specimens and his more than three thousand barometrical observations he was enabled to trace these bowlders to their source in the mountains, and to determine the laws of their distribution and the coincidence of these with the laws of the moraines on the glaciers. The main results were published in the *Bulletin de la Société des Sciences Naturelles de Neufchâtel*, and in Comte d'Archiac's *Histoire de la Géologie*. He next made soundings in the Lake of Neufchâtel, and published a fine topographical map of its subaqueous basin.

After the political revolution of 1848, he came to this country and settled in Cambridge, Mass. He first became extensively known here by a course of lectures on "Comparative Physical Geography in its Relation to the History of Mankind," delivered before the Lowell Institute in Boston, in the winter of 1848–49. These were translated by Professor Felton, and published in the volume entitled "Earth and Man." He was employed for some years by the Massachusetts Board of Education to deliver lectures in the Normal Schools and before the Teachers' Institutes, and thus began the reform in the method of studying and teaching geography. In 1854 he was elected Professor of Physical Geography and Geology in the College of New Jersey, and removed to Princeton in 1855, where he continued to reside. He was also appointed lecturer in the State Normal School at Trenton. He delivered courses of lectures in the Theological Seminary at Princeton, in the Union Theological Seminary at New York, and before the Smithsonian Institution at Washington, D. C.

In addition to the discharge of his duties as Professor, he continued

the work which he had begun in New England, the barometrical measurement of the mountains. He not only measured the height of the White and the Green Mountains, the Adirondacks and the Catskills, but he investigated the physical structure and elevation of the entire Alleghany system. The results of these summer excursions appeared in papers prepared for the Smithsonian Institution, the American Association, and the National Academy; also in articles in Silliman's Journal, and in special maps. He first determined the true height of Mount Washington, of the Black Mountains in North Carolina, and of the Green Mountains in Vermont. He introduced into this country the improved barometers now employed, and organized the system of meteorological observations, first under the care of the Smithsonian Institution, which has now grown into the admirable "Signal Service." He prepared for the Smithsonian Institution the very extensive series of meteorological tables now so generally employed. It was from his suggestion that the first deep-sea soundings of the Atlantic were made by our government. He published a large series of Wall Maps, and a series of Geographies, which have revolutionized the study of geography in this country. He was the author of the Introduction to Johnson's Physical Atlas, and was one of the editors of Johnson's Cyclopædia. His Maps and Geographies received the gold medal, the highest honor awarded, at Paris in 1878; and the medal of progress, a special honor, was given him at the exhibition at Vienna, in 1873. He was a member of the National Academy in this country, was an Honorary Member of the Geographical Society of France, and an Associate Member of the Royal Academy of Turin and of numerous other societies. His last work was "Creation, or the Biblical Cosmogony in the Light of Modern Science." It was finished only a few days before his death. He had been in declining health for several years, and died on February 8, 1884. In 1867 he married a daughter of the late Governor Haines, of New Jersey, who still survives him.

A simple extract from the minutes of the Faculty of the College of New Jersey will show the impression produced by him upon those with whom he came in contact, and this judgment is confirmed by numerous other testimonials:—

"His life-work was prosecuted with such intellectual vigor, indefatigable energy, conscientious fidelity, and distinguished success, that, among the eminent men of science of which the present age has been so prolific, the name of our departed colleague will ever occupy a conspicuous position. His character commanded the esteem of all within

the wide circle of his acquaintance. In deportment he was ever a model of propriety, dignified yet courteous, decided in his convictions yet modest in expressing them, considerate not only of the rights but of the feelings of all with whom he was associated, never unkind in word or act, and one of whom no one ever spoke or thought unkindly, singularly guileless and unselfish, a pure-minded, large-hearted, loving, and lovable Christian gentleman. His sincere, humble, childlike piety gave an attractive charm to all his conduct and conversation, and no one could be associated with him without feeling its elevating, refining, and ennobling influence. It was fitting that such a life should be crowned by the production of a work that will be prized by sincere seekers after truth respecting the works and the word of God, — an exhibition of the harmony of science and revealed religion."

ANDREW ATKINSON HUMPHREYS.

It falls to the lot of few men to encounter responsibilities so weighty and so diverse in character as those which rested upon General Humphreys at different periods of his long professional career; and of fewer still, to make of each new responsibility a new title to distinction.

Soldiers will most admire the general whose thoughtful intellect organized victory while others slept, and whose fiery energy led him into the thickest of the fight, until, like the heroes of mythology, he seemed to bear a charmed life.

Administrators will appreciate the skill displayed in systematizing the Coast Survey Office; in directing the Pacific Railroad explorations to a prompt and successful termination; and, after the war was over, in welding together the remnants of two distinct Corps of Engineers, and creating from them a united body fitted to meet the responsibilities devolved by law upon the organization.

Scientists will see his highest titles to fame in his personal investigations of the great questions involved in the construction of the Pacific Railroad; in the protection of the alluvial region of the Mississippi against overflow; in the deepening of the channels at the mouths of that river; and in the many other problems which engaged his attention before the cares of his high office as Chief of the Corps rendered it impossible to find leisure for such studies; — but they will also gratefully remember his appreciation of

the needs of science, and his care to aid its votaries whenever his position afforded the opportunity.

Personal friends who were associated with him intimately in private life, and knew his sterling independence of character, his contempt of all shams, his breadth of intellect, his appreciation of good in others, his generosity in according full credit whenever it was due, his inbred courtesy, which extended beyond forms and was an integral part of himself, — in a word, who knew the man, — will place these qualities above all others, because they constituted the basis upon which his unobtrusive greatness was founded.

Andrew Atkinson Humphreys was born in Philadelphia on November 2, 1810. His grandfather and father had both been distinguished in the public service as Naval Constructors, and each finally became chief of that Corps. The boy was admitted to the Military Academy, under Colonel Thayer as Superintendent, in 1827, and was graduated in 1831. His mind was one of those which mature slowly; and his standing, thirteenth in a class of thirty-three members, was no gauge of his real ability. He was assigned to the Second Artillery; but after serving mostly at Southern stations, and taking part in the Florida war, his health suffered severely, and he resigned his commission in 1836.

He adopted civil engineering as his profession; but when the Corps of Topographical Engineers was created, in 1838, he was appointed one of the First Lieutenants of the new organization. After various duties on the Great Lakes, and serving again in the Florida war, he was ordered to Washington in 1842; where he remained for two years as assistant in the Bureau of his own Corps, and for five years in charge of the Coast Survey Office under Professor Bache as Superintendent.

In 1850, he was selected to direct the topographical and hydrographical survey of the delta of the Mississippi, and the investigations to determine the most practicable plan for securing it against inundation, and for deepening the channels at the mouths. While prosecuting this work in 1851, Captain Humpheys was prostrated by a sun-stroke, which unfitted him for active duty for about two years. During the latter part of this time he travelled in Europe, and carefully studied the experience of many centuries on similar works for improving the Po, the Rhine, the Vistula, and other rivers.

Immediately after his return, in the summer of 1854, in addi-

tion to the Mississippi investigations, he was placed in charge of the explorations and surveys for determining the most practicable route for a railroad from the Mississippi River to the Pacific Ocean. From this date until the breaking out of the war, he performed an amount of professional labor which will be appreciated only by those who had personal knowledge of it at the time. Burdened with these two great national works and with the direction of subsequent explorations in the West, he was also an active member of the Light House Board, and served on two different commissions charged with important duties connected with the Military Academy, beside making special reports upon various works of internal improvement, which exhibit profound study and great ability. His mind seemed to work like a machine which required neither rest nor repairs; but his bodily health suffered from his intense application.

Of General Humphreys's war record this is not the place to speak. He served with the Army of the Potomac during the whole of its checkered history, and won a reputation which places him confessedly among the greatest soldiers the country has produced.

His last mental labor (1882–83) was the preparation of two volumes of the Scribner series, treating of the operations subsequent to the battle of Gettysburg, which have recently been compared to Cæsar's Commentaries by one of our best read military critics. During this period, Major-General Humphreys was either performing the duties of Chief of Staff of the Army or commanding the Second Corps; and it is fortunate indeed that he found time to write what will always be regarded as a military classic covering the most important operations of the war.

After the termination of hostilities General Humphreys was charged with an examination of the condition of the Mississippi levees, with a view to deciding what could best be done by the government to repair the damages and neglects caused by the war. On August 8, 1866, he was appointed Chief of Engineers with the rank of Brigadier-General in the regular service.

He held this office for thirteen years, serving also as a member of several boards and commissions charged with highly important duties. This period was one of transition in the history of the Corps of Engineers. The two corps which had existed before the war had been consolidated in 1863. Many of the most distinguished officers had been killed during the war, and their places were supplied by recent graduates of the Military Academy, whose period of service

spent in active campaigning had afforded no experience on works of construction, on surveys, or on special investigations.

The great changes in ordnance and the introduction of armor plating upon ships of war, rendered necessary a complete revision of our system of sea-coast defence. Works of internal improvement were undertaken upon a gigantic scale, calling for the earnest and systematic efforts of the Corps, both individually and as a body, to meet in this branch of duty the just expectations of the War Department and of Congress.

Never before had so responsible duties devolved upon the Chief of Engineers, but it was soon seen that the hand of a master was at the helm. The work of the general office was divided into four divisions, and an officer of special fitness was placed in charge of each. The old responsible board of Engineers for Fortifications was revived, with the distinguished names of Barnard, Cullum, Tower, and Wright as its *personnel.* Officers of rank and experience were selected for the charge of important districts and duties, according to merit as shown by their records in the department; and soon, under his careful attention, everything was working as smoothly as if the great convulsion caused by four years of civil war had never shaken the organization.

General Humphreys's individual contributions to science, and his care to advance its interests, were appreciated. In 1857, he was elected a member of the American Philosophical Society, Philadelphia; in 1862, an honorary member of the Imperial Royal Geological Institute of Vienna; in 1863, a Fellow of the American Academy of Arts and Sciences, Boston. In the same year, his name was placed on the list of the original corporators of the National Academy of Sciences. In 1864, he was elected an honorary member of the Royal Institute of Science and Arts of Lombardy, Milan. He was also a corresponding member of the Geographical Society of Paris; of the Austrian Society of Engineer Architects; and of the New Orleans Academy of Sciences. In 1880, he was elected an honorary member of the Italian Geological Society. The degree of LL. D. was conferred upon him by Harvard College in 1868.

In the regular service, besides the ordinary promotion in his Corps, he received the brevets of Colonel, Brigadier-General, and Major-General for gallant and meritorious services in the battles of Fredericksburg, Gettysburg, and Sailor's Creek.

He was married in 1839 to his cousin, Miss Rebecca Hollingsworth, and in his home the happiest hours of his life were spent.

There he always found rest from his labors in an atmosphere of love not often of this world; and when, on December 27, 1883, his final summons came, suddenly as the soldier would have wished, his sons and daughter were able to gather round and support their mother in her affliction.

When, upon his own application in 1879, his name was placed on the retired list of the Army, it was universally felt that one of the great men of the age had entered upon a merited rest. During a long life he had always ranged himself on the side of right, justice, and truth; and no personal considerations had ever hampered him when he felt that duty required a strong and decided stand. With all this strength, he was one of the kindest and most generous of men, and he possessed a personal magnetism which never failed to win the regard of those thrown into close relations with him. Indeed, the closer those relations, the stronger were the feelings of admiration and love engendered.

WILLIAM AUGUSTUS NORTON.

William Augustus Norton was born in East Bloomfield, N. Y., October 25, 1810, and died, September 21, 1883, after an illness of but a few days, within a month of the completion of his seventy-third year.

In 1827 he entered the Military Academy at West Point, where he graduated with high honors, and, in 1831, was promoted Second Lieutenant of Fourth Artillery, and assigned to duty as Acting Assistant Professor of Natural Philosophy in the Military Academy. He filled this position until 1833, with the exception of a few months, when he served with his regiment in the "Black Hawk War." In 1833 he resigned his position in the army, and was appointed Professor of Natural Philosophy and Astronomy in the University of the City of New York. This position he filled until 1839. He was afterwards Professor of Mathematics and Natural Philosophy in Delaware College, Newark, Delaware. This post he held for ten years, when he was elected President of the College, and served in this capacity during the year 1850. He then went to Brown University, Providence, Rhode Island, where he had charge of the Department of Natural Philosophy and Civil Engineering. In 1852 he was elected Professor of Civil Engineering in Yale College; and in the autumn of that year he entered upon his duties with a class of twenty-six students, who had followed their instructor from Brown University.

From that time, to the day of his death, he was ever found at his

post of duty, and many of his old pupils now filling responsible positions throughout the country will testify to the practical value of his instruction, to his great capacity as a teacher, and to his character as a man.

By his death the Sheffield Scientific School thus loses its oldest and one of its most widely known and beloved instructors. A teacher of more than fifty years' experience, an earnest and careful investigator, the school has had almost from its very inception — over a period of more than thirty years — the benefit of his skill and zeal. With its growth and rapid development he is identified, and to his faithful and devoted labors its success and reputation are largely due.

A teacher's best testimonial is the esteem and respect of his pupils, his best reward their love and confidence, and in this respect Professor Norton stood very high. No teacher ever had more loyal pupils. It has been the privilege of the writer to be his pupil, afterwards his colleague, — always his friend, — and during that period of seventeen years he has never met or known any student to entertain or suffer any doubt of Professor Norton's entire impartiality, his skill and fidelity as a teacher, or his friendly interest. With a manner peculiarly genial and endearing in the class-room, frank and manly always and at times almost jovial, he imparted to every pupil something of his own enthusiasm, and made each one feel that his instructor was also a personal friend. No student ever acted upon this impression and found it to fail. Ever ready with suggestion, advice, encouragement, and aid, young at heart himself and believing thoroughly in the young men under his charge, he was more to them than the subjects he taught, and his personal influence was better than books. Many of his old pupils will learn of his death with keenest sorrow, and will feel his loss as that of a friend.

Professor Norton was not a man whose work began and ended in the class-room. His educational and scientific contributions were numerous and important. Among these the chief published works are a "Treatise on Astronomy, Spherical and Physical," 1839, and a "First Book of Natural Philosophy and Astronomy," 1858. Of these, the first is a very complete and thorough treatise, which has passed through several editions.

His scientific memoirs were contributed mostly to the American Journal of Science, or the Philosophical Magazine of London, or were read at meetings of the American Association for the Advancement of Science, or of the National Academy of Sciences. Of these, the following are some of the more important: —

Terrestrial Magnetism American Journal of Science, Second Series, Vol. IV.

Periodical Variations of the Declination and Directive Force of the Magnetic Needle. American Journal of Science, 1855.

Ericsson's Caloric Engine. American Journal of Science, 1853.

Donati's Comet, two memoirs. American Journal of Science, 1859 and 1861

Molecular Physics, two memoirs. American Journal of Science, 1864 and 1872.

Principles of Molecular and Cosmical Physics. American Journal of Science, 1870.

The Corona seen in Total Elipses of the Sun. American Journal of Science, 1870.

Physical Constitution of the Sun. American Journal of Science, 1871.

Dynamical Theories of Heat. American Journal of Science, 1873.

Laws of the Deflection of Beams exposed to a Transverse Strain, tested by Experiment. Proceedings of American Association, 1870.

Physical Theory of the Principle of the Lever Proceedings of American Association, 1870.

Results of Experiments on the Set of Bars of Wood, Iron, and Steel, after a Transverse Stress. Two papers read before the National Academy of Sciences (April, 1874, and April, 1875). A succinct statement of the general conclusions of the two papers published in the American Journal of Science, April, 1876.

Results of Experiments on Contact Resistance. Read before National Academy of Sciences, April, 1876; published in American Journal of Science, June, 1876.

The above list sufficiently indicates the scope and character of Professor Norton's scientific labors. Those of them which pertain to engineering subjects are valuable contributions to the science of which he was so long a teacher. His investigation of Ericsson's Caloric Engine was thorough and masterly. Made at a time when extravagant expectations were widely entertained with regard to the new motor, his conclusions, expressed in the paper of 1853, are referred to and quotod to-day as one of the best expositions of the true nature, character, and future of the hot-air engine.

His experiments upon the set and transverse strength and deflection of bars of wood, iron, and steel, constitute an important and valuable addition to engineering science. The experiments were conducted with care and skill, and the value of the results has since been repeatedly acknowledged, and the results themselves incorporated into standard text-books. These papers are clear, precise, and definite both in statement and description, — qualities characteristic of all of Professor Norton's work, whether in or out of the class-room.

Of his numerous contributions to the American Journal of Science, comprising some of the most earnest work of his life, that journal speaks as follows (November, 1883): —

"His earliest memoir was in the forty-sixth volume of the first series, and was on the mode of formation of tails of comets. The manner of action of a solar repulsion in producing the comet's tails was developed at length. Some of the ideas, though original with Professor Norton, had been anticipated by Olbers and Bessel. A series of papers followed upon the relations between the distribution of heat on the earth and the phenomena of terrestrial magnetism.

"From these he was led on to further discussion of magnetic action over the earth, and of like action, as he argued, in the body of the sun, and in the formation of the comas and tails of comets. These papers included especially an elaborate discussion of the famous comet of 1858.

"After this followed a series of papers on molecular physics, in which, starting from a few elementary assumptions, he arranged in one system the various phenomena of physics, explaining the gaseous, liquid, and solid forms of matter, the various phenomena of electricity and magnetism, of light, heat, attraction, crystallization, and chemical action; also explaining terrestrial, cometary, and solar physics, the whole worked out in detail. Many of his conceptions and arguments are in direct opposition to widely accepted theories. But if some, or even if all of them shall, in the end, fail to be accepted as truths of nature, yet these memoirs will continue to testify to his love of truth, his painstaking labor, and his complete grasp of the problems to be solved."

In addition to the special purely scientific work above mentioned, Professor Norton was, in 1859, appointed engineer on the part of the State of Connecticut to determine the boundary line in controversy between this State and that of New York.

Of late years Professor Norton's contributions have been few, owing to his almost complete absorption in the preparation of a work which should present in systematic shape the views and conclusions above alluded to. Upon this work, containing the ripest results of his life of study, he based his claim to scientific reputation. He spoke of it always with enthusiasm, regarding his views as having passed out of the region of mere theory and as being capable of conclusive demonstration, and he ardently hoped that he might live long enough to complete the work. This we believe he did, but his sudden death has prevented his superintending its publication. It is to be hoped that it will yet see the light, and constitute, as he always hoped it would, his best claim to scientific reputation.

Professor Norton needs, however, no such work as his best claim

to remembrance. That claim is best founded on his daily work as a beloved teacher and on his personal character as a true and high-minded man.

As a teacher the writer can speak from personal experience of his rare capacity, and any enthusiasm he might well be betrayed into while on this topic would be heartily indorsed by every one of his former pupils living to-day. And, as with the best teachers, the greatest advantages were unconsciously imbibed by his pupils from personal contact, — the unconscious influence of high ideals, of love of truth and honor, of personal integrity, of scrupulous exactness, — these were lessons daily enforced, and more valuable than any of those he so well knew how to extract from the text-book or illustrate on the blackboard. His patience and courtesy were unfailing. No student, however trying or dull, ever heard from him an impatient or sarcastic word. Throughout his long career as a teacher, he never had the ill will of a single pupil, or any of those collisions quite as often due to the lack of sympathy of the teacher as to the wilfulness of the scholar. With perfect gentleness and courtesy, a thoroughness which spared no pains, and a clearness of exposition which, in the writer's experience, is very rare, he took every student with him in the prescribed course, and sent him away at graduation not only a wiser but a better man, as well as a personal and enthusiastic friend.

Professor Norton was married, in 1839, to Miss Elizabeth Emery Stevens, of Exeter, N. H., with whom, for more than forty years, he enjoyed that household happiness and content for which his kind and gentle nature so eminently fitted him. To that little household of two every student of his was always welcome, and all know how good it was to be there. There he dropped the professor, and his students found always a hearty welcome, and a genial, sympathizing friend, — young at heart as themselves, and interested in all their plans and prospects.

The record of this long and useful life, the lofty aims and high character which lay back of it, the simple faith and sincere convictions which guided it, the manly, genial qualities of mind and heart which adorned it, combine to make it one which claims and holds a foremost place in that long list of honored names — faithful teachers, sincere investigators, and high-minded men — of which Yale College has a right to be and is most justly proud. The influence of such lives is the best heritage of universities, and their memories are a tower of strength to the institution which claims them, as well as an inspiration and example to the students and colleagues who cherish them.

J. LAWRENCE SMITH.

J. Lawrence Smith was born near Charleston, S. C., December 17, 1818. At an early age he manifested great taste for mathematics; when four years old he could solve simple problems in addition and multiplication with great rapidity. This was some time before he could read. At eight years of age he was prepared for the study of algebra, and at thirteen years he was studying calculus. His knowledge and taste for mathematics continued throughout life. He pursued his studies in the best private schools of Charleston; afterward he was sent to the University of Virginia, where he enjoyed facilities for the indulgence of his taste for mathematics. In the latter part of his academic career he devoted himself to the higher branches of physics, mixed mathematics, and chemistry, studying the last rather as a recreation. He selected civil engineering as a profession, and after devoting two years to the study of its various branches in connection with geology and mining engineering, he was employed as an assistant engineer on the railroad projected at that time between Cincinnati and Charleston. This pursuit not proving congenial with his scientific tastes, he determined to study medicine. After studying three years, he was graduated Doctor in Medicine by the Charleston Medical College, an institution possessing at that time a corps of distinguished medical teachers. Dr. Smith then went to Europe, where he devoted three years more to the study of medicine. During all this time he continued his devotion to those departments which first enlisted his scientific affections. He studied physiology under Flourens and Longet; chemistry under Orfila, Dumas, and Liebig; physics under Pouillet, Desprez, and Becquerel; mineralogy and geology under Elie de Beaumont and Dufrenoy. While in Europe Dr. Smith prosecuted original researches on certain fatty bodies. His paper on Spermaceti, in 1843, at once stamped him as an experimental inquirer. On his return to Charleston, in 1844, he commenced the practice of medicine, and delivered a course of lectures on toxicology before the students of the Charleston Medical College. He also established the Charleston Medical and Surgical Journal, which proved a success.

But the State needing his services as assayer of the bullion that came into commerce from the gold-fields of Georgia and North and South Carolina, he accepted this duty, and relinquished the practice of medicine. He also gave a great deal of attention to agricultural chemistry. The great beds of marl on which the city of Charleston

stands early attracted his attention. He first pointed out the large amount of phosphate of lime in these marls, and was one of the first to ascertain the scientific character of this immense agricultural wealth. Dr. Smith also made a valuable and thorough investigation into meteorological conditions, character of soils, and culture, affecting the growth of cotton. His report on this subject was so valuable that in 1846 he was appointed by President Buchanan, in response to a request of the Sultan of Turkey, to teach the Turkish agriculturists the proper method of cotton culture in Asia Minor. On arriving in Turkey, Dr. Smith was chagrined to find that an associate on the commission had induced the Turkish government to undertake the culture of cotton near Constantinople. Unwilling to associate his name with an enterprise which he felt satisfied would be a failure,—the event justified his judgment,—he was on the eve of returning to America, when the Turkish government tendered him an independent position as Mining Engineer, with most liberal provisions. He performed the duties of this position for four years, with such signal success that the Turkish government heaped upon him decorations and costly presents. Since 1846 the Turkish government has continued to receive large revenues from his discoveries of emery, chrome ores, coals, etc. His papers on these subjects, read before learned societies and published in the principal journals of Europe and America, gave him a high position among scientific men. His discovery of emery in Asia Minor destroyed the rapacious monopoly of this article at Naxos, in the Grecian Archipelago, extended its use, and greatly reduced its price. His studies on emery and its associate minerals led directly to its discovery in America. In Massachusetts and North Carolina a large industrial product of emery is now carried on. To Dr. Smith justly belongs the credit of having done almost everything for these commercial enterprises by his successful researches on emery and corundum.

Dr. Smith investigated a great many Turkish resources. His paper on the "Thermal Waters of Asia Minor" is of great scientific value. In 1850 Dr. Smith invented the Inverted Microscope. This instrument, with his ingenious eyepiece micrometer and goniometer, is an important improvement; it is especially valuable in chemical work and culture experiments. This instrument has been unjustly figured and described in some works as Nachet's Chemical Microscope.

After Dr. Smith's return to America, his *Alma Mater*, the University of Virginia, called him to the chair of Chemistry, made vacant by the resignation of Prof. R. E. Rogers, in 1852. While dis-

charging the duties of his chair, he, in connection with his assistant, George J. Brush, performed the valuable and much needed work of revising the Chemistry of American Minerals. Having married a daughter of Hon. James Guthrie, of Louisville, Kentucky, Professor Smith resigned his chair in the University of Virginia, and adopted Louisville as his home. In 1854 he was elected to the chair of Chemistry in the Medical Department of the University of Louisville, made vacant by the resignation of Prof. B. Silliman. He filled this chair with signal success for several years, finally resigning it, and devoting his time to scientific research. For a number of years he was President of the Louisville Gas Works, and had the scientific charge of them.

Professor Smith had a private laboratory, which was one of the most complete and best equipped laboratories in this country. In 1855 he published a valuable Memoir on Meteorites. Since that time he has given special attention to these bodies. His private collection of meteorites was one of the largest in the world, and he was regarded as one of the highest authorities on this subject. Professor Smith was one of the commissioners of the United States to the Paris Exposition of 1867, and to the Vienna Exposition in 1873. His report on "The Progress and Condition of Several Departments of Industrial Chemistry" was wellnigh exhaustive.

In 1873 he issued an interesting work containing the more important of his scientific researches. Since this volume was published he has contributed a large number of valuable papers to various scientific journals. Professor Smith was very ingenious in devising new apparatus and methods of analysis. While much of his work was of a practical kind, he yet preferred original research in the less cultivated field. Of late years he was especially interested in the rare elements, and while studying Samarskite he discovered what he thought to be a new element, which he named Mosandrum. In 1878 he published an account of his researches on this subject, which attracted much attention among scientists.

In 1879 Professor Smith was elected Corresponding Member of the Academy of Sciences of the Institute of France, to succeed Sir Charles Lyell. He also received honors from the principal scientific bodies of the world. He was a member of the American National Academy of Sciences; the Chemical Society of Berlin; the Chemical Society of Paris; the Chemical Society of London; the Société d'Encouragement pour l'Industrie Nationale; the Imperial Mineralogical Society of St. Petersburg; the American Association for the Advancement

of Science; the British Association for the Advancement of Science; the Polytechnic Society of Kentucky; the Boston Society of Natural History; the American Academy of Arts and Sciences; the American Philosophical Society; the American Bureau of Mines; the Société des Sciences et des Arts de Hainaut; and of the Royal Society of Göttingen. He was Chevalier de la Legion d'Honneur; Member of the Order of Nichan Iftahar of Turkey; Member of the Order of Medjidiah of Turkey; and Chevalier of the Imperial Order of St. Stanislas, of Russia.

In 1874 he was President of the American Association for the Advancement of Science.

Professor Smith was a most indefatigable worker; his more important original researches number nearly one hundred, besides numerous addresses, lectures, and communications to secular and scientific papers on various scientific subjects. In 1881, on account of failing health, he ceased active work in the laboratory; but his zest for science was not dulled. As late as June, 1883, he published two valuable papers, namely, "Methods of Analyzing Samarskite," and "Peculiar Concretion occurring in Meteoric Iron." Much of his work of late was not left in a suitable condition for publication, and unfortunately will be lost to the scientific world. For two or three years he had been in declining health from a chronic affection of the liver; but he was seldom confined to his house. On the 1st of August, 1883, a severe attack of his disease compelled him to go to bed. After an illness of more than two months, characterized by the most patient, uncomplaining endurance, he peacefully and painlessly passed away, Friday, October 12, 1883, at three P. M. In accordance with his request, no eulogy was pronounced, but with a simple burial service his body was interred.

Professor Smith was of imposing presence and great dignity, strong, manly, self-reliant, pure-hearted, withal one of the most modest, unostentatious of men, — a simple, genial Christian gentleman. To those who knew him, or ever felt the charm of his presence, he was scarcely less endeared by his genial virtues than admired for his great powers. In him were united great talents and profound knowledge, with such graces of character as modest unselfishness and the most spotless integrity. His hospitality was unbounded, his love for children great; his courtesy and gallantry to ladies partook of the chivalry of former ages. He was most generous with his apparatus, and any one manifesting an interest in science was sure of help and encouragement from him. For many years he was a consistent member of

the Walnut Street Baptist Church. He was active in every benevolent and charitable work. His charity knew no sect nor creed, but his ear and purse were open to all real suffering. He founded and largely endowed the Baptists' Orphan Home of Louisville, thereby erecting a monument more noble and enduring than marble or brass.

Professor Smith said, "Life has been very sweet to me. It comforts me. How I pity those to whom memory brings no pleasure!" He had "set his house in order," saying he knew it would be but a short time before death would claim him; but he was ready to go at any hour or day. He leaves the memory of a pure life and a heart full of "exercised humanity."

FOREIGN HONORARY MEMBERS.

JOACHIM BARRANDE.

In the department of the Haute-Loire, on the borders of the central plateau of France, between Auvergne and the Vivarais, lies the little town of Saugues, where, on the 11th of August, 1779, Joachim Barrande was born. Graduating among the first scholars of the Polytechnic School at Paris, he was appointed engineer at Decize (Nièvre), and there constructed an aqueduct (*pont-canal*) over the river Loire that gave him a celebrity among the proficients in that department of science. The presentation of Barrande to the Dauphin, the Duc d'Angoulême, occurred during his stay at Decize, which place the Duc visited in the course of his travels through France. The Dauphin was much impressed by the character, the manners, and the great learning of the young engineer, and a little later, when a preceptor was desired for the instruction of the Comte de Chambord in science, he recommended Barrande warmly to the King, Charles X., for that position; the literary and religious education of the heir of the elder Bourbon family was given already in charge to Tarin, Bishop of Strasbourg. This unsolicited nomination to a place eagerly sought by many savants of that time filled Barrande with joy, and he accepted it with all the grave responsibilities he foresaw in the future, but without a thought that he was thus devoting himself to perpetual exile. At the Tuileries he organized a chemical and physical laboratory for the use of his royal pupil, but the revolution of 1830 soon put an end to his residence in this palace; the mob invaded his laboratory and

broke up his furnaces and retorts, electric machines, etc., and Barrande left France in company with his pupil. They remained in England, and in Scotland at Holyrood Castle, and in 1832 the prince was established in the ancient palace at Prague, the chateau of Hradschin.

During the stay in England and Scotland Barrande perfected his knowledge of the English language, which he spoke with ease. The French proverb, "À quelque chose malheur est bon," never had a happier application than in his example. In establishing their residence at Prague the Bourbon family carried with them the man who was to make celebrated forever the Silurian basin of Bohemia, and to cause it to become the classic ground of the most ancient fossil formations of the terrestrial globe. Barrande immediately began to decipher the geologic volume open before him. He recalled all his recollections of the geology of the environs of Paris, and of the centre of France; the lectures of the College of France, the Garden of Plants, and the Sorbonne; he brought to mind the great principles of natural history he had heard from the mouth of Georges Cuvier, Alexander Brongniart, Constant Prevost, and De Jussieu. But all this was of little help now; he was before a nature entirely new, and as yet untouched by scientific research. Everything was to be done. He did not hesitate, but went resolutely to work, and all his excursions with his pupil (or we may say with his two pupils, for the elder sister of the Comte de Chambord, Louise Marie Thérèse de France, later Duchess of Parma, went with them) were directed to the study of the rocks in the environs of Prague. Everything was collected in these scientific excursions; plants, insects, shells, birds, reptiles, mammals, all were good, and the two pupils were endless questioners. Barrande replied as his store of varied knowledge gave occasion, often modestly saying, "We will study that together." Geology soon became their favorite science, and the excursions were planned with a view to the best localities for fossils, such as Skrej, Zlichov, and Wiskocilka. The collections soon filled to overflowing the rooms devoted to study. Something must be done, and Barrande bought a house, Kleinseite, No. 419 Choteksgasse, so celebrated since, where, during forty-five years and more, he had placed the largest and richest collection of paleozoic fossils in the world.

Very gradually the observations of Barrande took the form of systematic classification, which allowed him to find his way in the labyrinth of the ancient rocks of Bohemia. Many points still remained obscure, when, in 1840, he procured a copy of Murchison's "Silurian

System." In the fossils published in this celebrated book, by the care of Agassiz, of Sowerby, and especially of Lonsdale, he was happy to find the forms he had collected so abundantly in Bohemia. His classifications agreed with those of England; the groups of Longmynd, of Llandeilo, Mayhill, Aymestry, Dudley, Wenlock, and Ludlow, of the English geologists, were also found in the beds of the environs of Prague; and, as he said later, it was in gratitude for the service rendered him by the "Silurian System," that he adopted the title of "Système Silurien du Centre de la Bohême."

Meanwhile the royal Bourbon family had left Prague for Goritz, and, later still, for Frohsdorf. Barrande was chiefly domiciled at Prague; he had also an apartment in Paris, at No. 6 Rue Mézières, and later at 22 Rue de l'Odéon. All geologists and paleontologists of any reputation in either the Old or New World have visited Barrande in these apartments, and were always received there with the perfect courtesy of a gentleman of the old *régime*.

Barrande was soon master of the German tongue, and several of his memoirs were written in German. In order to direct more precisely the search for fossils that the workmen in the quarries of Bohemia were to undertake, and avoid being deceived, he learned to speak the Tcheque.

The cunning of the peasants and their desire for gain are shown in the following anecdotes. Ten or twelve intelligent workmen were employed by the year to collect fossils. Barrande showed them the beds of rock, the forms of the fossils he especially wished to obtain, and indicated their locality. In order to excite their emulation, he promised the largest reward for fossils coming from certain places where they were rare. It happened that several of these men tried to deceive him, bringing a certain number of fossils that they said were found in the locality for which the highest price had been offered. Barrande quietly placed the fossils before him, and, while talking with them, arranged them in groups. He then said, very politely, "You are trying to deceive me: these fossils," pointing to a group, "come from such a place, and not where you pretend to find them." The workmen looked at one another astonished. They had been very careful to assure themselves, by a spy employed for that purpose, that M. Barrande was at his house; they knew no one had seen them take the fossils. Certainly he was a wizard,—an astrologer who had a pact with the Devil! As they were caught in their attempted deception, they confessed. Barrande treated them with great kindness, as he always did his inferiors, and bade them do so no more,—pardoned

them, and paid them the highest price for the fossils, although they were not worth it; but he said, "Let this be a lesson to you: another time I shall dismiss you from my employ."

One of these men was so successful in deceiving him, that he was fond of telling the story. One day this man appeared in great distress. "What is the matter?" said Barrande. "Oh! my wife is dangerously ill." "Here, take this money and go to the doctor and the apothecary." A few days later, he came all in tears, — his wife was dead, he said. Barrande quickly gave him another sum of money to meet the funeral expenses. Time went on, and he came no more; but one day he appeared, looking anxious, scratching his ear, and had evidently a demand to make. "Well, what is it now?" "O, I cannot stay any longer all alone; I want to marry again." "Have you found any one suitable?" "Yes." "Well, here is money that will help you to celebrate your new marriage." The cunning peasant went away delighted. Some time after, Barrande went to the village where the peasant lived, and, in talking with the Syndic or Mayor, he said, "Such a one has had the misfortune, poor fellow, to lose his wife." "Not at all: his wife is alive." "I know," said Barrande, "but it is his second wife." "I assure you you are mistaken, for his first wife has never even been ill." Barrande laughed heartily, said nothing, but did not employ the man again.

Barrande edited his great work himself. Having placed the first two volumes with booksellers, their vexatious and absurd exactions and commissions caused him to withdraw them, and he subsequently sold his own works. His liberality was great, and he frequently presented these magnificent and costly volumes to public institutions, and even to individuals. In America he gave the four large volumes last issued, entitled "Acéphalés," to the Boston Society of Natural History, and to Jules Marcou, James Hall, Charles A. White, J. S. Newberry, F. V. Hayden, and C. King. He spared neither money, labor, nor effort that this work might be as perfect as any that had been published. He employed the best draughtsmen, especially Humbert, who had been long under the good training of the celebrated paleontologist, Deshayés. Humbert passed nearly twenty-five years with Barrande, and died at his work. He had established a French printing-press at Prague, and the work is very correct; so much so, that it could not possibly have been done better in Paris.

Taken one with another, all the expenses included, each volume represented an outlay of twenty thousand francs. This would make for the twenty-two volumes published an expense of four hundred

and forty thousand francs. Hardly forty thousand were returned to him by those who purchased the work.

The patrimony of Barrande was but small, and to meet this great expense, much beyond the means of a private individual, and such as only a government was able to undertake, Barrande spent the income of all his appointments; that received from Charles X., that from the Comte de Chambord as preceptor, and that as manager of the fortune of the elder branch of the Bourbons. For the prodigious fact remains to be told, that Barrande, besides the scientific work which he did without any aid save that of a copying clerk to whom he sometimes dictated some of his descriptions, administered a fortune of nearly sixty millions of francs, part of which was landed property scattered from the environs of Vienna to Venice and the Château de Chambord. The journeys he made to fulfil these duties, to Goritz, Frohsdorf, Munich, Venice, Modena, Parma, Paris, and Chambord, may be numbered by hundreds, and the great capacities of the man are well shown by the onerous and absorbing nature of his two so widely different occupations, and also by the placid and serene elegance of his bearing under such great stress of work as lay upon his shoulders. Only a giant's strength could calmly lift and carry such enormous burdens.

He lived with great simplicity, putting all he had in his collections, books, and above all in publishing his works. The Comte perceived, doubtless, that his former master, now become his most favored friend, must spend more than his appointments in his scientific work; and when the head of the house of France visited Prague, where he found, among the multitude of specimens, some difficulty in being seated for want of room, he used to say, in leaving a large sum of money behind him, it was his subscription to the Silurian System of Bohemia. Each volume of this great work was justly dedicated to the generous prince, and in the latest one, Prague, 8 December, 1881, he says, "The unusual number of these illustrations [361 plates] shows clearly the extent and the efficacy of your royal munificence, without which all my efforts and all my personal sacrifices would have been powerless to accomplish my task." By this liberality, the last representative of the illustrious house of the elder Bourbons has earned the gratitude of all the actual and future geologists and paleontologists the world may furnish.

The influence of Barrande on the progress of geology and paleontology was not limited to the centre of Europe, but includes Spain, Scandinavia, Great Britain, and North America. He not only published some fossils of Canada and Newfoundland, but the large place

that the primordial fauna occupies in America to-day, and its true position in the scale of strata, are due to him. The late Dr. Emmons had recognized a special fauna in his "Taconic System," but there were neither enough species, nor sufficiently good specimens to show the principal characters, especially in the great family of Trilobites. Besides, a passionate and unjust opposition had arisen against the discoveries of this pioneer in American stratigraphy. Barrande, with great impartiality and loyalty, declares: "Dr. Emmons first announced the existence of a fauna anterior to that which had been established in the Silurian System, as characterizing the Lower Silurian division, which I have named the second fauna. It is then just to recognize this priority, and I think it all the more proper to state it at this moment, that it has remained unclaimed until now." *

Another great service rendered to geology by Barrande is his discovery and "Doctrine des Colonies." Like all new observations and facts that arise and overturn admitted conclusions, this has caused a vigorous and persistent opposition, first by paleontologists and then by geologists; but Barrande always replied victoriously, by facts, to this opposition, and several geologists of great experience in the field, not only admit the "doctrine of colonies," but consider it the greatest discovery that has been made in stratigraphy since "Strata Smith" discovered in 1799 that strata could be identified by their fossils.

Barrande, like Agassiz, was a pupil of Cuvier; and both have excelled all their contemporaries in the exactness of their descriptions, the delicacy of their observations, and above all in the multiple comparison of all the forms, of all the characters, which was the chief glory of their illustrious master, and it may be said that both remained faithful through life to the doctrines professed by the great French naturalist.

It is impossible in a limited article to do justice to a savant and a man whose life was so full and so prolonged. So courteous, generous, benevolent, and full of goodness,—of a wide toleration, although immovable in his convictions, whether of politics, science, or religion,—Barrande remained always true to himself. He was during his last years the most ancient household member of the eldest branch of the Bourbons; having lived faithfully through the few good and many evil days of the oldest kingly dynasty that remains in our time, he could not long outlive the last male representative of that royal line: and six weeks after the death of his king, who was also his pupil and

* Documents Anciens et Nouveaux sur la Faune Primordiale et le Système Taconique en Amérique, p. 225, Paris, February, 1861.

his friend, for the Comte de Chambord was all of these to Barrande, the greatest French geologist of the century died, in his eighty-fourth year, on the 5th of October, at the Chateau of Frohsdorf, near Vienna, under the same roof where his royal master had just terminated his honorable life of exile, always respected even by his political enemies. As a last proof of friendship the Comte de Chambord appointed Barrande executor to his will; and in carrying out this last trust, he took a cold that rapidly degenerated into paralytic pneumonia.

The splendid collection of fossils, and the large and valuable library, were left by will to the Museum of Natural History of Bohemia, and also a sum of ten thousand florins, which has been more than doubled by his family, — a brother and sister, for Barrande was never married. His great work, already far advanced, will be completed under the direction of the Bohemian Museum. The seventh volume, in two parts, on Gasteropoda, will soon be issued by Dr. Waagen; the eighth volume, in three parts, on Echinoderms and the Colonies, is to appear in two years, and is also under the supervision of, and edited by, Dr. Waagen. Volume IV., the last of the series, (for the publication of the different parts of his work has been quite irregular,) will be edited by Dr. Novák, and is devoted to Bryozoa and Corals. The whole work forms a series of twenty-nine or thirty volumes, or "tomes," as Barrande called them. The edition is of two hundred and fifty copies only; of which more than fifty have been presented to public libraries.

The motto on the title-page of each volume reads, "C'est ce que j'ai vu, — le témoin au juge," and in his "Defense des Colonies" he says: "La science est loin d'être achevée, elle se fait lentement, en surmontant les difficultés de l'observation et aussi en se dégageant péniblement des entraves que notre intelligence humaine et bornée se crée à elle-même par ses théories préconçues."

Noble words from one who has penetrated so far into the secrets of the earth's history, and has unveiled them without prejudice, and without fear of disturbing received and prevailing opinions.

JEAN-BAPTISTE-ANDRÉ DUMAS.

Jean-Baptiste-André Dumas was born at Alais, in the south of France, July 14, 1800. His father belonged to an ancient family, was a man of culture, and held the position of clerk to the municipality of Alais. The son was educated at the college of his native place, and appears to have been destined by his parents for the naval service. But the anarchy and bloodshed which attended the downfall of the

First Empire produced such an aversion to a military life that his parents abandoned their plan, and apprenticed him to an apothecary of the town. He remained in this situation, however, but a short time; for, owing to the same sad causes, he had formed an earnest desire to leave his home, and, his parents yielding to his wish, he travelled on foot to Geneva in 1816, where he had relatives who gave him a friendly welcome, and where he found employment in the pharmacy of Le Royer.

At that time Geneva was the centre of much scientific activity, and young Dumas, while discharging his duties in the pharmacy, had the opportunity of attending lectures on botany by M. de Candolle, on physics by M. Pictet, and on chemistry by M. Gaspard de la Rive; and from these lectures he acquired an earnest zeal for scientific investigation. The laboratory of the pharmacy gave him the necessary opportunities for experimenting, and an observation which he made of the definite proportions of water contained in various commercial salts, although yielding no new results, gained for him the attention and friendship of De la Rive. Soon after we find the young philosopher attempting to deduce the volumes of the atoms in solid and liquid bodies by carefully determining their specific gravities, and thus anticipating a method which thirty years later was more fully developed by Hermann Kopp.

About this time young Dumas had the good fortune to render an important service to one of the most distinguished physicians of Geneva, whose name is associated with the beneficial uses of iodine in cases of goitre. It had occurred to Dr. Coindet that burnt sponge, then generally used as a remedy for that disease, might owe its efficacy to the presence of a small amount of iodine; and on referring the question to Dumas, the young chemist not only proved the presence of iodine in the sponge, but also indicated the best method of administering what proved to be almost a specific remedy. It was in connection with this investigation that Dumas's name first appears in public. The discovery produced a great sensation, and for many years the manufacture of iodine preparations brought both wealth and reputation to the pharmacy of Le Royer.

Soon after, Dumas formed an intimacy with Dr. J. L. Prévost, then recently returned from pursuing his studies in Edinburgh and Dublin, and was induced to undertake a series of physiological investigations, which for a time withdrew him from his strictly chemical studies. Several valuable papers on physiological subjects were published by Prévost and Dumas, which attracted the notice of Alexander von Humboldt, who on visiting Geneva, in 1822, sought out Dumas and

awakened in him a desire to seek a wider field of activity than his present position opened to him. In consequence he removed to Paris in 1823, where the reputation he had so deservedly earned at Geneva won for him a cordial reception at what was then the chief centre of scientific study in Europe. La Place, Berthollet, Vauquelin, Gay-Lussac, Thenard, Alexandre Brongniart, Cuvier, Geoffroy St. Hilaire, Arago, Ampère, and Poisson, all manifested their interest in the young investigator. Dumas was soon appointed Répétiteur de Chimie at the École Polytechnique, and also Lecturer at the Athenæum, an institution founded and maintained by public subscription, for the purpose of exciting popular interest in literature and science; and from this beginning his advancement to the highest position which a man of science can occupy in France was extremely rapid.

In 1826 he married Mdlle. Herminie Brongniart, the eldest daughter of Alexandre Brongniart, the illustrious geologist, an alliance which not only brought him great happiness, and at the time greatly advanced his social position, but also in after years made his house one of the chief resorts of the scientific society of Paris. The many who have shared its generous hospitality will appreciate how greatly, for more than half a century, Madame Dumas has aided the work and extended the influence of her noble husband.

In 1828–29 Dumas united with Théodore Olivier and Eugène Péclet in founding the École Centrale des Arts et Manufactures, an institution which met with great success, and in which, as Professor of Chemistry, Dumas rendered most efficient service for many years, and in 1878 had the very good fortune to aid in celebrating the fiftieth anniversary of his own foundation; and to see it acknowledged as among the most important and efficient scientific institutions of the world. In 1832 Dumas succeeded Gay-Lussac as Professor at the Sorbonne; in 1835 he succeeded Thenard at the École Polytechnique; and in 1839 he succeeded Deyeux at the École de Médecine. Thus before the age of forty he filled successively, and for some time simultaneously, all the important professorships of chemistry in Paris except one. This exception was that of the College of France, with which he was never permanently connected, although it was there that he delivered his famous course on the History of Chemical Philosophy, when temporarily supplying the place of Thenard.

Dumas early recognized the importance of laboratory instruction in chemistry, for which there were no facilities at Paris when he first came to what was then the centre of the world's science; and in 1832 founded a laboratory for research at his own expense. This laboratory, first

established at the Polytechnic School, was removed to the Rue Cuvier in 1839, where it remained until broken up by the Revolution of 1848. The laboratory was small, and Dumas would receive only a few advanced students, and these on terms wholly gratuitous. Among these students were Piria, Stas, Melsens, Leblanc, Lalande, and Lewy, with whose aid he carried on many of his important investigations. By the Revolution of 1848 Dumas's activities were for a time diverted into political channels; but under the Second Empire his laboratory was re-established at the Sorbonne, and in 1868 was removed to the École Centrale.

The political episode of Dumas's life was the natural result of an active mind with wide sympathies, which recognizes in the pressing demands of society its highest duty. The political and social upheaval of 1848 seemed at the time to endanger the stability in France of everything which a cultivated and learned man holds most dear; and Dumas was not one to consider his own preferences when he felt he could aid in averting the calamities which threatened his country. Immediately after the Revolution of February, he accepted a seat in the Legislative Assembly offered him by the electors of the Arrondissement of Valenciennes. Shortly afterwards the President of the Republic called him to fill the office of Minister of Agriculture and Commerce. During the Second Empire he was elevated to the rank of Senator, and shortly after his entrance into the Senate he became Vice-President of the High Council of Education. In order to reform the abuses into which many of the higher educational institutions of Paris had fallen, he accepted a place in the Municipal Council of Paris, over which he subsequently presided from 1859 to 1870.

In 1868 Dumas was appointed Master of the Mint of France, but he retained the office only during a short time, for with the fall of the Second Empire, in 1870, his political career came to an abrupt termination. The Senate had ceased to exist, and in the stormy days which followed, the Municipal Council had naturally changed its complexion; and even at the Mint, the man who had held such a conspicuous position under the Imperial government was obliged to vacate his place. Some years previously he had resigned his professorships because his official positions were incompatible with his relations as teacher, and now, at the age of seventy, he found himself for the first time relieved from the daily routine of official duties, and free to devote his leisure to the noble work of encouraging research, and thus promoting the advancement of science. He had reached an age when active investigation was almost an impossibility, but his commanding position gave

him the opportunity of exerting a most powerful influence, and this he used with great effect. In early life he had been elected, in 1832, a member of the Academy of Sciences in succession to Serullas; in 1868 he had succeeded Flourens as its Permanent Secretary; and in 1875 he was elected a member of the French Academy as successor to Guizot, a distinction rarely attained by a man of science.

It was, however, as Permanent Secretary of the Academy of Sciences that Dumas exerted during the last years of his life his greatest influence. He was the central figure and the ruling spirit of this distinguished body. No important commission was complete without him, and on all public occasions he was the orator of the body, always appropriate, always eloquent. In announcing Dumas's death to the Academy, M. Rolland, the presiding officer, said: —

"Vous savez la part considérable que Dumas prenait à vos travaux et vous avez bien souvent admiré, comme moi, la haute intelligence et la tact infini avec lesquels il savait imprimer à nos discussions les formes modérées et courtoises inhérentes à sa nature et à son caractère. Sous ce rapport aussi la perte de Dumas est irréparable et crée dans l'Académie un vide bien difficile à combler. Aussi, longtemps encore nous chercherons, à la place qu'il occupait au Bureau avec tant d'autorité, la figure sympathique et vénérée de notre bien-aimé Secrétaire perpétuel."

And while Dumas was still occupying his conspicuous position in the Academy, one of the most distinguished of his German contemporaries* wrote of him: "An ever-ready interpreter of the researches of others, he always heightens the value of what he communicates by adding from the rich stores of his own experience, thus often conveying lights not noticed even by the authors of those researches."

When the writer last saw Dumas, in the winter of 1881–82, the great chemist had still all the vivacity of youth, and it was difficult to realize his age. He took a lively interest in all questions of chemical philosophy, which he discussed with great earnestness and warmth. There was the same fire and the same exuberance of fancy which had enchanted me in his lectures thirty years before. At an age when most men hold speculation in small esteem, I was much struck with his criticism of a contemporary, who, he said, had no imagination,

* A. W. Hofmann, in Nature, February 6, 1880, to whose admirable and extended biography the writer is indebted for much of the material with which this notice has been prepared.

although he spoke with the highest praise of his experimental skill. At that time Dumas showed no signs of impaired strength. But during the following year his health began to fail, and he died on the 11th of April, at Cannes, where he had sought a retreat from the severity of the winter climate of Paris.

Dumas was one of the few men whose greatness cannot be estimated from a single point of view. He was not only eminent as an investigator of nature, but even more eminent as a teacher and an administrator. Beginning the study of chemistry at the culmination of the epoch of the Lavoisierian system, and regarding, as he always did, the author of that system with the greatest admiration, he nevertheless was the first to discover the weak point in its armor and inflict the wound which led to its overthrow. Without attempting to detail Dumas's numerous contributions to chemical knowledge, we will here only refer to three important investigations, which produced a marked influence in the progress of chemical science.

While still in Geneva, Dumas, as has been said, made numerous determinations of the densities of allied substances, with a view to discovering the relations of what he called their molecular or atomic volumes; and it is no wonder to us that the problem proved too complex to be solved at that time. After his removal to Paris he took up the much simpler problem which the relations of the molecular volumes of aeriform substances present, and his paper "On Some Points of the Atomic Theory," which was published in the *Annales de Chimie et de Physique* for 1826, had an important influence in developing our modern chemical philosophy. Gay-Lussac had previously observed, not only that the relative weights of the several factors and products concerned in a chemical process bear to each other definite proportions, but also that, when the materials are aeriform, the relative volumes preserve an equally definite and still simpler ratio. Moreover, on the physical side, Avogadro, and afterwards Ampère, had conceived the theory, that in the state of gas all molecules must have the same volume. It was Dumas who first saw that these principles furnished an important means of verifying the molecular and atomic weights.

"I am engaged," he writes, "in a series of experiments intended to fix the atomic weights of a considerable number of bodies, by determining their density in the state of gas or vapor. There remains in this case but one hypothesis to be made, which is accepted by all physicists. It consists in supposing that, in all elastic fluids observed under the same conditions, the molecules are placed at equal distances, i. e.

that they are present in them in equal numbers. An immediate consequence of this mode of looking at the question has already been the subject of a learned discussion on the part of Ampère," — and Avogadro as the author subsequently adds, — "to which, however, chemists, with the exception perhaps of M. Gay-Lussac, appear to have given as yet but little attention. It consists in the necessity of considering the molecules of the simplest gases as capable of a further division, — a division occurring in the moment of combination, and varying with the nature of the compound."

Here, it is obvious, are the very conceptions which form the basis of our modern chemical philosophy; and at first we are surprised that they did not lead Dumas at once to the full realization of the consequences which the doctrine of equal molecular volumes involves in the interpretation of the constitution of chemical compounds, and to the clear distinction between "the physically smallest particles" and "the chemically smallest particles," or the molecules and the atoms, as we now call the physical and the chemical units. This distinction is implied throughout Dumas's paper already quoted, and is illustrated by a striking example in the introduction to his treatise on "Chemistry applied to the Arts," published two years later; but the ground was not yet prepared to receive the seed, and more than a quarter of a century must pass before the full harvest of this fruitful hypothesis could be reaped.

There were, however, two important incidental results of this investigation from which chemical science immediately profited. One was a simple method of determining with accuracy the vapor densities of volatile substances which has since been known by Dumas's name. The other was a radical change in the formula of the silicates. On the authority of Berzelius, who based his opinion chiefly on the analogy between the silicates and the sulphates, the formula SiO_3 had been accepted as representing the constitution of silica. But from the density of both the chloride and the fluoride of silicon Dumas concluded that the formula was SiO_2, a conclusion which is now seen to be in complete harmony with the scheme of allied compounds. To Berzelius, however, the new views appeared wholly out of harmony with the system of chemistry which he had so greatly assisted in developing, and he opposed them with the whole weight of his powerful influence, and so far succeeded as to prevent their general adoption for many years. Still, "the new mode of looking at the constitution of silicic acid slowly but surely gained ground, and it is now so firmly rooted in our convictions, that the younger generation of chemists will

scarcely understand the pertinacity with which this innovation was resisted." *

But if this investigation of gas and vapor densities brought a great strain upon the dualistic system, the second of the three great investigations of Dumas, to which we have referred, led to its complete overthrow. The experimental results of this investigation would not be regarded at the present day as remarkable, and cannot be compared either in breadth or intricacy with the results of numerous investigations of a similar character which have since been made. The most important of these results were the substitution products obtained by the action of chlorine gas on acetic acid. They were published in a series of papers entitled "Sur les Types Chimiques," and the capital point made was that chlorine could be substituted in acetic acid for a large part of the hydrogen without destroying the acid relations of the product; and the inference was, that the qualities of a compound substance depend not simply on the nature of the elements of which it consists, but also on the manner or type according to which these elements are combined.

To the chemists of the present day these results and inferences seem so natural that it is difficult to understand the spirit with which they were received forty years ago. But it must be remembered that at that time the conceptions of chemists were wholly moulded in the dualistic system. It was thought that chemical action depended upon the antagonism between metals and metalloids, bases and acids, acid salts and basic salts, and that the qualities of the products resulted from the blending of such opposite virtues. That chlorine should unite with hydrogen was natural, for no two substances could be more unlike; but that chlorine should supply the place of hydrogen in a chemical compound was a conception which the dualists scouted as absurd. Even Liebig, the "father of Organic Chemistry," warmly controverted the interpretation which Dumas had given to the facts he had discovered. Liebig himself had successfully investigated the chemical relations of a large class of organic products. He had, however, worked on the lines of the dualistic system, showing that organic substances might be classed with similar inorganic substances, if we assume that certain groups of atoms, which he called "compound radicals," might take the place of elementary substances. In the edition of the organic part of Turner's Chemistry bearing his name, Organic Chemistry is defined as the "Chemistry of Compound Radicals,"

* Hofmann, *loc. cit.*

and the formulæ of organic compounds are represented on the dualistic system. Liebig's conceptions were therefore naturally opposed to those advanced by Dumas, but it is pleasant to know that the controversy which arose never disturbed the friendly relations between these two noble men of science, who could approach the same truth from different sides, and yet have faith that each was working for the same great end. In his commemorative address on Pelouze, Dumas expresses towards Liebig sentiments of affectionate regard, and Liebig dedicates to Dumas, with equal warmth, the German edition of his "Letters on Chemistry."

By the second investigation, as by the first, although Dumas gave a most fruitful conception to chemistry, he only took the first step in developing it. His conception of chemical types was very indefinite, and Laurent wrote of it, a few years later: "Dumas's theory is too general; by its poetic coloring, it lends itself to false interpretations; it is a programme of which we await the realization." Laurent himself helped towards this realization, and in his early death left the work to his associate and friend Gerhardt, who pushed it forward with great zeal, classifying chemical compounds according to the four types of hydrochloric acid, water, ammonia, and marsh gas. Hofmann, Williamson, Wurtz, and many others, greatly aided in this work by realizing many of the possibilities which these types suggested; and thus modern Structural Chemistry gradually grew up, in which the types of Dumas and Gerhardt have been in their turn superseded by the larger views which the doctrine of quantivalence has opened out to the scientific imagination. It is a singular fact, however, that, while the growth began in France, the harvest has been chiefly reaped by Germans; and that, although in its inception the movement was strongly opposed in Germany, its legitimate conclusions are now repudiated by the most influential school of French chemists.

The third great investigation of Dumas was his revision of the atomic weights of many of the chemical elements, and in none of his work did he show greater experimental skill. His determination of the atomic weight of oxygen by the synthesis of water, and of that of carbon by the synthesis of carbonic dioxide, are models of quantitative experimental work. To this investigation, as to all his other work, Dumas was directed by his vivid scientific imagination. In his teaching, from the first, he had aimed to exhibit the relations of the elementary substances by classing them in groups of allied bodies; and at the meeting of the British Association in 1851 he had delighted the chemical section by the eloquence and force with which

he exhibited such relations, especially triads of elementary substances; such as chlorine, bromine, and iodine; oxygen, sulphur, and selenium; phosphorus, arsenic, and antimony; calcium, barium, and strontium; in which not only the atomic weight, but also the qualities of the middle member of the triad, were the mean of those of the other two members. Later, he came to regard these triads as parts of more extended series, in each of which the atomic weights increased from the first to the last element of the series, by determinate, but not always by equal differences, the values being, if not exact multiples of the hydrogen atom according to the hypothesis of Prout, at least multiples of one half or one quarter of that weight. There can be no doubt that these speculations were more fanciful than sound, and that Dumas did not do full justice to earlier theories of the same kind; but with him these speculations were merely the ornaments, not the substance of his work, and they led him to fix more accurately the constants of chemistry, and thus to lay a trustworthy foundation upon which the superstructure of science could safely be built.

That exuberance of fancy to which we have referred made Dumas one of the most successful of teachers, and one of the most fascinating of lecturers. It was the privilege of the writer to attend the larger part of two of his courses of lectures given in Paris in the winters of 1848 and 1851, and he remembers distinctly the impression produced. Besides the well-arranged material and the carefully prepared experiment, there was an elegance and pomp of circumstance which added greatly to the effect. The large theatre of the Sorbonne was filled to overflowing long before the hour. The lecturer always entered at the exact moment, in full evening dress, and held to the end of a two hours' lecture the unflagging attention of his audience. The manipulations were entirely left to the care of a number of assistants, who brought each experiment to a conclusion at the exact moment when the illustration was required. An elegance of diction, an appropriateness of illustration, and a beauty of exposition, which could not be excelled, were displayed throughout, and the enthusiasm of a French audience added to the animation of the scene.

To the writer the lectures of Dumas were brought in contrast to those of Faraday. Both were perfect of their kind, but very different. Faraday's method was far more simple and natural, and he excelled Dumas in bringing home to young minds abstruse truths by the logic ot vell-arranged consecutive experiment. With Dumas there was no attempt to popularize science; he excelled in clearness and elegance of exposition. He exhausted the subject which he treated, and was able

to throw a glow of interest around details which by most teachers would have been made dry and profitless.

Two volumes of Dumas's Lectures have been published; one comprises his course on the Philosophy of Chemistry, delivered at the College of France in 1836; the other contains only a single lecture, accompanied by notes, entitled "The Balance of Organic Life," which was delivered at the Medical School of Paris, August 20, 1841. In both these volumes will be found the beauty of exposition and the elegance of diction of which we have spoken, and they are models of literary style. But of course the sympathetic enthusiasm of the great man's presence cannot be reproduced by written words.

The lecture on "The Balance of Organic Life" was probably the most remarkable of Dumas's literary efforts. It dealt simply with the relations which the vegetable sustains to the animal kingdom through the atmosphere, which, though now so familiar, were then not generally understood; and the late Dr. Jeffries Wyman, who heard the lecture, always spoke of it with the greatest enthusiasm.

As might be expected, Dumas's oratory found an ample field in the Chamber of Deputies and in the Senate; and whether setting forth a project of recasting the copper coinage or a law of drainage, or ridiculing the absurd theories of homeopathy, he riveted the attention of his colleagues as completely as he had entranced the students at the Sorbonne.

In the early part of his life, Dumas was a voluminous writer, and in 1828 published the "Traité de Chimie appliquée aux Arts," in eight large octavo volumes, with an atlas of plates in quarto. But besides this extended treatise, the two volumes of Lectures just referred to are his only important literary works. He published numerous papers in scientific journals, which, as we have seen, produced a most marked effect on the growth of chemical science. But the number of his monographs is not large compared with those of many of his contemporaries, and his work is to be judged by its importance and influence rather than by the extent of the field which it covers.

In his capacity of President of the Municipal Council at Paris, of Minister of Agricultural Commerce, of Vice-President of the High Council of Education, and of Perpetual Secretary of the Academy of Sciences, Dumas had abundant opportunity for the exercise of his administrative ability, and no one has questioned his great powers in this direction; but in regard to his political career we could not expect the same unanimity of opinion. That he was a liberal under Louis Philippe, and a reactionist under Louis Napoleon, may possibly be reconciled with a fixed political faith and an unswerving aim for

the public good; but his scheme for "civilian billetting" (by which wealthy people having rooms to spare in their houses would have been compelled to billet artisans employed in public works) leads one to infer that his statesmanship was not equal to his science. Nevertheless, there can be no question about his large-hearted charity. He instituted the "Crédit Foncier," which flourishes in great prosperity to this day; he also founded the "Caisse de Rétraite pour la Vieillesse," and several other agricultural charities, which, though less successful, afford great assistance to aged workmen. Louis Napoleon used to say in jest that the whole of the War Minister's budget would not have been enough to realize M. Dumas's benevolent schemes; and once, half dazzled, half amused, by one of the chemist's vast sanitary projects, he called him "the poet of hygiene."

It was to be expected that a man working with such eminent success in so many spheres of activity, and at one of the chief centres of the world's culture, should be loaded with medals, and marks of distinction of every kind. It would be idle to enumerate the orders of knighthood, or the learned societies, to which he belonged, for, so far from their honoring him, he honored them in accepting their membership. It is a pleasure, however, to remember that he lived to realize his highest ambitions and to enjoy the fruits of his well-earned renown. France has added his name in the Pantheon

"AUX GRANDS HOMMES LA PATRIE RECONNAISSANTE."

OSWALD HEER.

OSWALD HEER, the most eminent investigator of the fossil plants and insects of the tertiary period, died on the 27th of September last, shortly after he had entered upon the seventy-fifth year of his age.

He was born at the hamlet of Nieder-Utzwyl, in Canton St. Gallen, Switzerland, August 31, 1809, passed most of his youth at Matt, in Canton Glarus, where his father was the parish clergyman, pursued his academic and professional studies at the University of Halle, and was ordained as minister of the Gospel in the year 1831. The next year he went to Zurich, where he resided for the rest of his life. Here he studied medicine for a time, but soon devoted himself seriously to entomology and botany, of which he was fond from boyhood. In 1834 he became Privat-docent of these sciences; in 1852, when the University of Zurich was developed, he became its Professor of Botany, and in 1855 he took a similar chair in the Polytechnicum. Most of his

earlier publications were entomological; and it was by the way of entomology that he entered upon his distinguished career as a paleontologist. His life-long friend, the eminent Escher von der Linth, appreciating his rare powers of observation, induced him to undertake the study of the fossil insects of the celebrated tertiary deposits of Oeningen. The results of his labors in this virgin field were published between the years 1847 and 1853. His attention had from the first been attracted to the plants associated with the insect remains. His first paleobotanical paper appeared in 1851; the three volumes of his *Flora Tertiaria Helvetiæ* were issued between 1855 and 1859; in 1862 his memoir on the fossil flora of Bovey-Tracey (England) was published in the Philosophical Transactions of the Royal Society, London. About the same time also appeared a paper in the Journal of the Geological Society on certain fossil plants of the Isle of Wight. For the benefit of his health, always delicate and then much impaired, he passed the winter of 1854–55 in Madeira, and on his return published a paper on the fossil plants of that island, and an article on the probable origin of the actual flora and fauna of the Azores, Madeira, and the Canaries. In this, and in his work, published in 1860, on Tertiary Climates in their Relation to Vegetation (which the next year appeared also in a French translation by his young friend Gaudin), Heer brought out his theory of a Miocene Atlantis. His more extensive and popular treatise upon past climates as illustrated by vegetable paleontology, his *Urwelt der Schweiz*, — a vivid portraiture of the past of his native country, — appeared in 1865, and afterwards in a revised French edition, with his friend Gaudin (who died soon after) for collaborator as well as translator. There was also an English translation by Heywood, published in 1876, and, indeed, it is said to have been translated into six languages.

In 1877 Heer completed his *Flora Fossilis Helvetiæ*, a square-folio volume, with seventy plates, which extended and supplemented his Tertiary Flora of that country, being devoted to the illustration of the fossil plants of the Carboniferous, the Triassic, the Jurassic, and the Cretaceous, as well as the Eocene formations.

The life-long delicacy of Heer's health prevented his making any extensive explorations in person. But materials for his investigation came to him in even embarrassing abundance, not only from his own country, — where, even before he was widely known, (as his fellow countryman and his distinguished fellow worker in paleobotany, Lesquereux, informs us,) a lady opened upon her property near Lausanne quarries and tunnels expressly for the discovery and collection of fossil

plants, and sent them by tons to Zurich, — but from all parts of the world, collections were pressed upon him, and his whole time and strength were given to their study. In this way he became interested in the Arctic fossil flora, of which he became the principal investigator and expounder. His first essay in the domain which he has made so peculiarly his own was in a paper on certain fossil plants of Vancouver Island and British Columbia, published in 1865; and in 1868 he brought out the first of that most important series of memoirs upon the ancient floras of Arctic America, Greenland, Spitzbergen, Nova Zembla, Arctic and Subarctic Asia, etc., which, collected, make up the seven quarto volumes of the *Flora Fossilis Arctica.* The seventh volume of this monumental work was brought to a conclusion only a few months before the author's death.

Heer's researches into the fossil botany of the tertiary deposits were very important in their bearings. They made it certain that our actual temperate floras round the world had a common birth-place at the North, where the continents are in proximity; they essentially identified the direct or collateral ancestors of our existing forest trees which flourished within the Arctic zone when it enjoyed a climate resembling our own at present; and they leave the similarities and the dissimilarities of the temperate floras of the Old and the New World to be explained as simple consequences of established facts. Thus Heer himself did away with his own hypothesis of a continental Atlantis by bringing to light the facts which proved that there was no need of it. And, while thus justifying the ideas which had been brought forward in one of the Memoirs of the American Academy (in 1859) before these fossil data were known, he was not slow to adopt and to extend the tentative views which he had confirmed.*

A list of Heer's scientific publications is given in the Botanisches Centralblatt, No. 5, for 1884. They are seventy-seven in number, besides the seven quarto volumes of the *Flora Fossilis Arctiea*, which comprise a considerable number of independent memoirs. These works make an era in vegetable paleontology. Their crowning general interest is that they bring the vegetation of the past into direct connection with the present.

Although he lived to a good old age, and was never inactive, Heer was for most of his life an invalid, suffering from pulmonary disease. For the last twelve years his work was carried on at his bedside or

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* The first and second volumes of the *Flora Fossilis Arctica* appeared in 1868–71. "Sequoia and its History," in which the earlier view was extended and made clearer, and Heer's results noted, was published in 1872.

from his bed, assisted by a devoted and accomplished daughter; he seldom left his house, except to pass the last two winters in the milder climate of Italy. Last summer, having finished his Arctic Fossil Flora, in the hope of recruiting his exhausted strength he was removed to the most sheltered spot on the shores of the Lake of Geneva, but without benefit. He died at Lausanne, at his brother's house, on the 27th of September, 1883. It has been well said of him, in a tribute which a personal friend and fellow naturalist paid to his memory, that "a man more lovable, more sympathetic, and a life more laborious and pure, one could scarcely imagine."

Heer was elected into the Academy in May, 1877. He is botanically commemorated in a genus of beautiful Melastomaceous plants, indigenous to Mexico.

FRANÇOIS-AUGUSTE-ALEXIS MIGNET.

François-Auguste-Alexis Mignet, whose name was added to our Foreign Honorary roll in 1876, died in Paris on the 24th of March last, at eighty-eight years of age. He had lived to be the senior member of the Institute of France, having been admitted to the Académie Française in 1836, and to the Academy of Moral and Political Sciences as early as 1832. Of this latter Academy he was, at his death, the Honorary Perpetual Secretary, after more than forty years of active service in that distinguished office. His discourses at the annual meetings of this Academy, as published from year to year, contain admirable sketches of the lives and characters of the eminent members with whom he was associated, and who had died before him. Talleyrand, De Tocqueville, Victor Cousin, and De Broglie, of France; Ancillon and Savigny, of Germany; Brougham and Macaulay, of England; and Edward Livingstone, of our own land, — were among the subjects of his brilliant *éloges*. But he was the author of larger and more substantial works of history and biography. In 1824 he published a notable History of the great French Revolution of 1789, and this was followed, from time to time, by many volumes relating to "The Spanish Succession," "The Abdication of Charles V.," "The Rivalry of Charles V.;" and other topics of general historical interest. A charming biography of Marie Stuart, and an excellent little Life of Benjamin Franklin, were also among the productions of his pen. He was a man of great accomplishments and many personal attractions, an eloquent speaker and a fine writer, and he will long be remembered as one of the most valuable and honored members of the Institute of France.

SIR EDWARD SABINE.

Sir Edward Sabine was born in Dublin, October 14, 1788. He died, June 26, 1883, at the great age of nearly ninety-five years. His grandfather and his uncle had served with distinction in the army, and he received his own education at the military colleges of Marlow and Woolwich. The exigencies of the service were urgent: so that he obtained his first commission in December, 1803, at the early age of fifteen. He was employed for a year at Woolwich, and then sent to Gibralter, where he remained until 1807. On his return, he was assigned to the Horse-Artillery, and ordered to various home stations until the war came with the United States, in 1813–14. In January, 1813, he was attached to a company in Canada. The ship in which he embarked was captured by a privateer, which was in its turn recaptured by a British frigate, and he reached Halifax in safety. Captain Sabine served with credit at Quebec, on the Niagara frontier, and at the attack on Fort Erie, and received honorable notice in the despatches of the commanding officer. The remainder of his military service was limited to the nine years following 1830, when the troubled condition of Ireland required his presence with his company or upon the staff. Though he reached the rank of Lieutenant-Colonel in 1841, and of General in 1874, the periods of his active professional life were only brief episodes in a career eminently scientific. "Peace hath her victories no less renowned than war": and the government early recognized in him the qualities and tastes which admirably adapted him to these peaceful conquests.

Captain Sabine was elected a member of the Royal Society of London, April 16, 1818. By the advice of the Council of this society, he was selected by the Admiralty to accompany the expedition of Commander John Ross, in 1818, in search of a Northwest Passage. His duty was to assist "in making such observations as may tend to the improvement of geography and navigation, and the advancement of science in general." On his return he published a description of twenty-eight species of birds collected in Greenland, and an account of the Esquimaux who inhabit its western coast. In 1821 the Copley Medal of the Royal Society was awarded to him for his scientific services, in which were included his measurements of the force of gravity by the vibrations of a pendulum, published in that year. In 1819, he was chosen to go with Lieutenant-Commander Parry on a second Polar Expedition. Parry has recorded his obligations to Sabine "for his valuable advice and assistance during the whole course of this voy-

age, to the credit of which his individual labors have so essentially contributed." The intensity of the magnetic force of the earth, the dip and declination of the magnetic needle, and the irregularities in its action produced by the iron in the ship, especially in latitudes where the directive force of the earth is feeble, were conspicuous among the subjects which interested Sabine and were discussed in his earlier publications.

The exact figure of the earth may be studied in three ways: 1. by inequalities in the moon's motion; 2. by measuring the lengths of a degree of the meridian in different latitudes; and 3. by the comparative values of the force of gravity in various places, as indicated by the pendulum. In the years 1821–23, Sabine, adopting the last method, vibrated his pendulum at numerous places between the equator and Spitzbergen, and the results of his experiments, spread over eighty degrees of latitude, were published, in 1825, in a thick quarto volume, by the Board of Longitude. For this laborious and able investigation Sabine received the Lalande Gold Medal from the Institut de France. Biot and Babbage have criticised this work; but the numerical value which Sabine assigned to the ellipticity of the earth is substantially sustained by all the experiments with the pendulum to the present time. In 1825 Captain Sabine and Sir John Herschel were appointed Commissioners to coöperate with a French Commission in order to ascertain the difference of longitude between the observatories of Greenwich and Paris, by means of optical signals. The value then obtained differs by only six tenths of a second of time from that now given by electric signals. In 1828, Sabine, Young, and Faraday were appointed "scientific advisers of the Admiralty."

The last forty-six years of Sabine's scientific activity were dedicated to the study of terrestrial magnetism. In 1834–37, he made, in conjunction with Rev. Humphrey Lloyd, or Captain J. C. Ross, a systematic magnetic survey of Ireland, Scotland, and England. The observations, the reductions, and the reports on the subject, published, with maps, by the British Association, were to a large extent his own work. In 1858–61, at the request of the British Association, he repeated the survey, with the assistance of Dr. Lloyd; and with the aid of Captain Evans calculated and reported the values of the dip, declination, and intensity. In his first Arctic voyage, Sabine had noticed with surprise that the magnetic intensity was diminishing in Baffin's Bay while he was moving northward. Hence he suspected that the pole of magnetic intensity was south of his position: a suspicion which was justified by observations made in New York in 1822, where the inten-

sity is greater than at Melville Island in the latitude of 74° N. In his earlier report of 1837 he placed the pole of intensity in the latitude of 52°, which is eighteen degrees south of the pole of dip. This result was deduced from a magnetic reconnoissance at long range. But it harmonizes with the theory of Gauss, and does not conflict with the observations of Captain (now General Sir) J. H. Lefroy, who laid closer siege to it in 1843.

In 1836, an appeal was made by Humboldt to the British government to establish at various places in its vast empire magnetical observatories similar to those then operating in Germany and Russia. Accordingly, in 1839–40, four of these observatories were instituted; viz. at Toronto, St. Helena, the Cape of Good Hope, and Hobarton. They were not intended to be permanent; and the period of their activity varied from three to ten years. Their work was reinforced by the Naval Scientific Expedition to the Antarctic Zone of Sir J. C. Ross and Lieutenant Moore. The observers were selected largely from the younger officers of the Horse-Artillery, and were instructed in their new work by Professor Lloyd at Dublin. It is sufficient to say that most of them acquired a scientific taste and reputation which introduced them to the Royal Society, while they have also risen to the highest rank in their profession. The appointment of Major Sabine as the general superintendent of this great scientific work was fortunate. He devoted twenty years of his life to the arrangement, discussion, and publication of the formidable mass of meteorological and magnetical observations which issued from these prolific observatories. Only a brave heart would have confronted this stupendous task, even with the liberal clerical aid furnished by the government. In the voluminous introductions to the twelve thick quarto volumes which issued from his office, Sabine investigated the periodical changes in the meteorological and magnetic elements, their secular variations, their irregular fluctuations, their relations to solar and lunar time, to disturbances in the sun, and to the aurora. The decennial period in the *amplitude* of the diurnal oscillation of the needle, which Lamont detected in his observations at Munich, reappeared in Sabine's materials, and was extended to the irregular disturbances, and later, by himself and others, to changes in the declination, dip, and intensity. Hansteen, from a larger series of observations, changes the period to eleven years. Meanwhile, Wolf had deduced from Schwabe's catalogue of solar spots a similar period in their number and magnitude About 1852 came the interesting announcement by Sabine, Wolf, Secchi, and Gautier, of a probable coincidence in the maxima of spot-

frequency and magnetic disturbance; Wolf not limiting the comparison to recent observations, though the earlier ones on both classes of phenomena are fragmentary.

In addition to his official work, Sabine continued his publication of a series of papers, which he began in 1840, under the title of "Contributions to a View of the Distribution of Magnetism over the Earth." The fifteenth contribution appeared as late as 1876, when its author was eighty-eight years old. In these contributions Sabine collected, arranged, and discussed an immense fund of observations, made by sea or land, in every latitude and longitude, printed or in manuscript, and drawn from innumerable sources, foreign and domestic, many of them inaccessible to the ordinary student. The observations were illustrated by maps, prepared in the office of the Admiralty, under the direction of Captain Evans of the Royal Navy. The astronomer Halley had attempted, with equal boldness, but with inadequate materials gathered in his own voyages, to make a rough sketch of the features of the earth's magnetism in 1701.

Allusion has been made in this notice to only the most important of the one hundred and three papers printed by Sabine. His mind and his pen were incessantly at work. Every subject connected with the physics of the globe interested and occupied him: the temperature of the depths of the ocean, the direction and force of its currents, and their influence on navigation; the influence of the Gulf Stream on the coasts of Europe and on the oceanic horizon; the barometrical measurement of mountains and their effect upon the plumb-line; the length of degrees of the meridian; the meteorology of Bombay; the winter storms of the United States; and the causes of mild winters. At the same time, he was not unmindful of the improvements going on, at home and abroad, in his own arm of the military service. Not less valuable were his services as the scientific adviser of his wife, the gifted translator of Humboldt's "Cosmos and Aspects of Nature," and of Dove's "Distribution of Heat over the Surface of the Earth." The societies which honored him with their highest offices brought him labor as well as distinction, and demanded of him the preparation of many addresses. He was the General Secretary of the British Association from 1839 to 1858, and its President in 1853. In 1846 he was made Foreign Secretary of the Royal Society, in 1850 its Vice-President and Treasurer, and its President between 1861 and 1871. The Royal Medal, then recently re-established by Queen Victoria, was awarded to him in 1849 for his contributions to the study of terrestrial magnetism; and the government created him a K. C. B. in 1869 for

his great services in the cause of science. Learned Academies abroad placed his name upon their distinguished rolls, and Universities at home crowned him with their highest honors. He was elected a Foreign Honorary Member of this Academy, May 28, 1867. His life was protracted for a few years after his physical strength was exhausted and his mind had been overshadowed by disastrous eclipse.

JOHANN FRIEDRICH JULIUS SCHMIDT.

Johann Friedrich Julius Schmidt was born at Eutin, in the Grand Duchy of Oldenburg, October 25, 1825, and was educated at the Hamburg Gymnasium. He developed very early in life a taste for the observation of natural phenomena, which was directed into astronomical channels, at the age of fourteen years, by his coming into possession of a copy of Schröter's work on the Moon, which so struck his attention that he at once began his first attempts at astronomical observation by sketching the lunar surface with a small telescope constructed by his father, which he steadied against a lamp-post. This work soon became his chief occupation; but was carried on with improved facilities, first by a telescope lent him by a gentleman interested in the progress of the young astronomer, and afterwards by the use of the instruments at the Altona and Hamburg observatories, to which latter place he went as an assistant to Rümker in 1842. In 1845 Schmidt went to Bilk, near Dusseldorf, where Benzenberg had established an observatory for the observation of meteors and the search for intra-Mercurial planets. His instrumental facilities here, however, were much restricted, the solicitude of Benzenberg lest the polish and lacquer of the principal telescope should suffer by handling practically prohibiting its use. Benzenberg died in 1846, and Schmidt went to Bonn as assistant to Argelander. Here his lunar work was somewhat interrupted, his time being largely occupied with observations of planets and comets, and with the meridian circle. He made, on the occasion of the total eclipse of the sun, July 28, 1851, important observations, in East Prussia, with reference to the phenomena which are now identified with the chromosphere, revealed more distinctly since that time by the spectroscope.

Later, Schmidt was appointed, on Argelander's recommendation, to the charge of a private observatory established at Olmütz by Baron von Unkrechtberg, provided with a small meridian circle and a five-inch refractor, with smaller telescopes and subsidiary apparatus. He began work here in June, 1853, and actively prose-

cuted work in the various directions in which he was interested until August, 1858, when, after a few months' sojourn at Vienna, where he observed in September and October Donati's comet, and in Trieste, he went to Athens, December 15, 1858, where he had been appointed Director of the Observatory. Here, as soon as the condition of the institution permitted, he began the voluminous series of observations, the results of which, published annually in the Astronomische Nachrichten, have become so familiar to astronomers, and afford such striking testimony to his industry and zeal.

Schmidt seems never to have been attracted to work in the mathematical or calculative fields of astronomy; one or two preliminary orbits of the comets of 1847 and 1848, and of the planet Egeria, being his only published work in this direction. From the start his inclination was strongly toward the observation of the physical phenomena of the heavenly bodies, and to this his favorite work he applied himself with an ardor and unwavering persistence which may be considered among the chief attributes of genius. His enormous industry is remarkable even in this industrious scientific age. The duration of his scientific life was forty-three years, and in this period, with only very moderate instrumental means, and scarcely any assistance, he has accumulated a mass of observation material which seems incomprehensible to a man of ordinary powers. His work on the moon alone, covering thirty-three years, would have appalled most men. Any one who will attempt to delineate even a very small portion of the lunar surface with an instrument of the size used by Schmidt, and with the amount of detail given by him, will appreciate the task achieved in his chart of the Lunar Mountains, published in 1878. The drawings and micrometrical measures of various portions of the moon, he accumulated for about a quarter of a century before he seriously contemplated forming a general chart. In 1865, he first resolved to lay down all his fragmentary surveys on a six-foot map, to see what parts had been neglected. In so doing he found how much was wanting, and how little he possessed; but, nothing daunted, devoted nine years more to the extension and repetition of his observations, and so industriously that his older work became of comparatively little importance. He then determined to conclude the labor and publish what he had already accomplished, as it was manifest that the filling in of all the detail visible in a six-foot refractor would surpass the powers of endurance, and require more than the lifetime, of a single individual. In 1874 he carried his chart to Berlin, and it excited so much interest that the German government undertook its publication. In point of com-

prehensiveness it far exceeds any other attempt of its kind. Thus, while Lohrmann's map includes about 7,200 craters, and Mädler's 7,800, Schmidt's chart includes the extraordinary number of nearly 33,000.

Next or perhaps equal in importance is Schmidt's series of observations on the variable stars, which extend from 1842 to 1883, and which probably outnumber those of all other observers of his time combined. It has been his practice to publish annually, in the Astronomische Nachrichten, the provisional results, and it seems peculiarly fitting that the same number of that journal which contains the announcement of his death contains also the last of this memorable series. Schmidt made several notable discoveries of new variables. The original records of his observations have been deposited in the Astro-Physical Observatory at Potsdam, and will form an almost inexhaustible treasure to future workers in this field.

In still another department, that of the solar phenomena, Schmidt was a remarkably fruitful and persevering observer. In 1857 he published the results of a continuous eleven-year series of observations on the sun-spots, which are simultaneous with, and serve to complete and supplement, those of Schwabe. He gives tables of the daily number of spots and groups, with remarks on special phenomena, and adds a discussion of them. His speculations on the possible connection of the sun-spot period with the varying position of the centre of gravity of the solar system with reference to the centre of the sun itself, have not met with general acceptance. During the last twenty years, also, this kind of observation has been perseveringly kept up by Schmidt, with the help in recent years of his assistant, Alexander Wurlisch.

The other labors of Schmidt, although important and in extent sufficient to absorb the whole time and energy of an ordinary man, can only be mentioned briefly here. He was a persistent observer from 1843 to 1879 of the phenomena pertaining to the Zodiacal Light; made very large contributions to the fund of observations of shooting-stars during the same period; published a thirteen years' series of observations on the Northern Light; determined micrometrically the positions of about three hundred nebulæ; made very elaborate drawings of the Great Nebula in Orion, and a chart of the surrounding region; has deposited at Vienna a beautiful drawing of the Milky Way; accumulated during forty years voluminous observations on the brightness of the principal planets, besides nearly six hundred drawings of the surface of Mars and Jupiter; made impor-

tant investigations on the subject of the twilight, based on his observations at Hamburg, Rome, Naples, and in Greece, from 1843 to 1864, obtaining very interesting results; published, as Annals of the Athens Observatory, important contributions to our knowledge of the physical phenomena of comets, and also on the Physical Geography of Greece; co-operated largely in the construction of Hour V. of the Berlin Academy Charts, the most elaborately worked of the series; made series of measures of the diameters of the various planets, as well as observations on Saturn's rings; and finally took a very large share in the work of position determinations of comets and asteroids.

Surely this devoted servant of science has well earned the tribute of admiration which astronomers universally pay to his memory. To make good his loss, not one, but several assiduous workers will be required in the various fields which he has so long and ardently cultivated.

Schmidt died of heart disease, being found dead in his bed, Thursday morning, February 7, 1884, after having passed the previous evening apparently in perfect health at the German Embassy at Athens. The funeral was made an occasion for national mourning, in which all classes sorrowfully participated.

GABRIEL GUSTAV VALENTIN.

Gabriel Gustav Valentin, for forty-five years Professor of Physiology at Berne, died in that city on the 23d of May, 1883. He was born of Jewish parents, at Breslau, on the 8th of July, 1810. He took his degree in medicine in his native city in 1832, and continued to practise his profession there till 1836, when he was called to the chair of Physiology at Berne. This position he held till 1881, when he resigned on account of ill health.

During his long peric l of scientific activity Professor Valentin made contributions to nearly every department of Physiology. We find him, for instance, in 1842, contributing to Wagner's Lexicon of Physiology articles on Secretion, Animal Electricity, Nutrition, Biliary Movement, and on Galvanism in its effects on the animal body and the tissues of the human and animal body. His associates in this important scientific undertaking were the brothers Weber, Purkinje, Lehmann, Ludwig, Von Siebold, Berzelius, Bischoff, Bidder, Frerichs, Leuckart, Volkmann, and many others of that band of devoted investigators whose labors during the middle of the present century contributed so

largely to place physiology in its proper position among the experimental sciences.

A glance through the annual reports on the progress of Physiology shows that the name of Valentin appears several times in nearly every year as a contributor to the periodical literature of this science. In addition to these labors, he found time to write a text-book of physiology, which was translated into English by Dr. Brixton.

His latest work seems to have been a series of articles entitled "Histiologische und Physiologische Studien," the publication of which in the Zeitschrift für Biologie continued as late as 1882.

CHARLES ADOLPHE WURTZ.

The sad intelligence of the death of this distinguished French chemist, on the 12th of May, comes to us by telegraph, just as we are completing this Report, and we have no time for an extended notice. He was not elected a Foreign Honorary Member of this Academy until the last annual meeting, so that his name has not yet appeared on our printed list. His death, following so closely that of Dumas, leaves a vacancy in the ranks of the French chemists which cannot soon be filled.

Wurtz was born at Strasburg, November 16, 1817, where he was educated. He became a student in the chemical department of the medical school of his native city in 1839, and took his degree there in 1843. Soon after he moved to Paris, where he began his chemical career as assistant to Dumas, and first acquired an independent position as Professor at the Agricultural Institute at Versailles. After the death of Orfila, in 1853, and the retirement of Dumas, in 1854, their chairs were united in that of Medical Chemistry, and given to Wurtz. He became Dean of the Medical Faculty in 1866, and subsequently was elected Professor of Chemistry at the Sorbonne.

It is, however, with the Medical School in Paris that Wurtz is chiefly identified, and his investigations were carried on in the laboratory of that institution. Under the influence of Laurent and Gerhardt, Wurtz's studies were early directed towards organic chemistry; and to him is due, in no small measure, the development of modern structural chemistry. Almost at the outset of his career, he discovered the remarkable reaction by which the primary amines are produced from the cyanates of the alcohol radicals, and thus gave prominence and greater definiteness to the ammonia type of chemical compounds.

Subsequently he studied the action of sodium on the iodides of the alcohol radicals. Previously, by the action of zinc on the iodide of ethyl and methyl, Frankland had succeeded in isolating hydro-carbon, which he regarded as the actual alcohol radical; but Wurtz, using a mixture of the iodide of two radicals, found that he obtained a homogeneous product, which was formed by a union of the two radicals. This left no doubt that Frankland's radical substance was also formed by the union of two molecules of methyl or ethyl, and rendered our views of the relations of such radicals much clearer than before. In order to define the radicals of organic chemistry more accurately, Wurtz introduced the term "rest," and enunciated the rule, which for a long time held an important place in the science, "that the atomicity of a compound radical is always equal to the number of hydrogen atoms, or their equivalents, which the rest may be regarded as having lost."

Soon after followed Wurtz's remarkable investigations on the glycols, and oxide of ethylene, by which he not only defined the diatomic alcohols, and gave us our first accurate knowledge of these bodies, but also developed the theory of types into the larger doctrine of quantivalence, in which he recognized the determining cause of molcular structure; and it was in the discussion on the constitution of lactic acid which followed this investigation that Wurtz made the distinction between basicity and atomicity. Subsequently, by the action of hydriodic acid on amylene, Wurtz obtained a product isomeric with amyl alcohol, and the investigation of this new substance resulted in defining the relations of the now well-known class of tertiary alcohols. We must not forget to mention also the synthesis of the oxygen bases, including that of choline, — so interesting as one of the proximate principles of the animal economy; also the synthesis of the aromatic acids, followed during these last years by a study of the condensation products from aldehyde, by which he isolated aldol and other compounds after the same type.

Among Wurtz's later investigations is one into which he was led by a controversy with some of his colleagues in the French Academy, in regard to abnormal vapor densities as bearing on the validity of the law of Avogadro. The discussion chiefly turned on the action of heat on hydrate of chloral, and by a most ingenious series of experiments Wurtz proved that aqueous vapor was present as such in the vapor of this substance, and therefore that the apparent abnormal vapor density of hydrate of chloral was due to disassociation.

This controversy indicated Wurtz's nearly isolated position among

the modern school of French chemists. As the writer has stated, in the notice of Dumas, the French school, as a rule, repudiate the legitimate consequences of the very movement which originated with their immediate predecessor. Wurtz, however, although with the strongest French sympathies, and while claiming chemistry as almost exclusively a French science,* saw throughout the inconsistency of this position, and, as he aided in developing, has sought to maintain in its integrity, the system of modern structural chemistry. Wurtz's volumes on the Philosophy of Chemistry, which have appeared in different languages under several titles, contain an elegant exposition of this system. Wurtz was also the author of several elementary treatises on Chemistry, the editor of a Dictionary of Chemistry, of the "Répertoire de Chimie Pure," and one of the editors of the "Annales de Chimie et de Physique." It would be impossible in a limited sketch to give more than the barest outline of his scientific and literary work. Indeed, previously to 1864 he had published seventy-three papers, as shown by the Catalogue of the Royal Society.

In 1867 Wurtz became a member of the Academy of Sciences, and in 1881–82 presided over that body. He received many distinguished honors, and a few years since was made Senator of France.

Since the last Report, the Academy has received an accession of nine new members; viz. four Resident Fellows, three Associate Fellows, and two Foreign Honorary Members. The list of the Academy corrected to the date of this Report is hereto added. It includes 193 Resident Fellows, 85 Associate Fellows, and 66 Foreign Honorary Members.

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* See the Introduction to his work on Chemical Philosophy.

LIST

OF THE FELLOWS AND FOREIGN HONORARY MEMBERS.

RESIDENT FELLOWS.—193.

(Number limited to two hundred.)

Class I.—*Mathematical and Physical Sciences.*—74.

Section I.—6.

Mathematics.

William E. Byerly,	Cambridge.
Benjamin A. Gould,	Cambridge.
Gustavus Hay,	Boston.
James M. Peirce,	Cambridge.
John D. Runkle,	Brookline.
Edwin P. Seaver,	Newton.

Section II.—14.

Practical Astronomy and Geodesy.

J. Ingersoll Bowditch,	Boston.
Seth C. Chandler, Jr.,	Cambridge.
Alvan Clark,	Cambridgeport.
Alvan G. Clark,	Cambridgeport.
George B. Clark,	Cambridgeport.
John R. Edmands,	Cambridge.
Henry Mitchell,	Boston.
Robert Treat Paine,	Brookline.
Edward C. Pickering,	Cambridge.
William A. Rogers,	Cambridge.
Arthur Searle,	Cambridge.
Leopold Trouvelot,	Cambridge.
D. C. Wendell,	Cambridge.
Henry L. Whiting,	Tisbury.

Section III.—39.

Physics and Chemistry.

A. Graham Bell,	Cambridge.
Clarence J. Blake,	Boston.
Francis Blake,	Auburndale.
John H. Blake,	Boston.
Thos. Edwards Clark,	Williamstown.
W. S. Clark,	Amherst.
Josiah P. Cooke,	Cambridge.
James M. Crafts,	Boston.
Charles R. Cross,	Boston.
William P. Dexter,	Roxbury.
Amos E. Dolbear,	Somerville.
Charles W. Eliot,	Cambridge.
Moses G. Farmer,	New York.
Thomas Gaffield,	Boston.
Wolcott Gibbs,	Cambridge.
Frank A. Gooch,	Cambridge.
Edwin H. Hall,	Cambridge.
Henry B. Hill,	Cambridge.
N. D. C. Hodges,	Salem.
Silas W. Holman,	Boston.
Eben N. Horsford,	Cambridge.
T. Sterry Hunt,	Montreal.
Charles L. Jackson,	Cambridge.
William W. Jacques,	Newburyport.
Leonard P. Kinnicutt,	Cambridge.
Joseph Lovering,	Cambridge.
Charles F. Mabery,	Cambridge.
Alfred Michael,	Medford.
William R. Nichols,	Boston.
John M. Ordway,	Boston.
William H. Pickering,	Boston.
Robert H. Richards,	Boston.
Edward S. Ritchie,	Brookline.
Stephen P. Sharples,	Cambridge.
Francis H. Storer,	Jamaica Plain.
John Trowbridge,	Cambridge.
Cyrus M. Warren,	Brookline.
Charles H. Wing,	Boston.
Edward S. Wood,	Cambridge.

Section IV.—15.

Technology and Engineering.

George R. Baldwin,	Woburn.
John M. Batchelder,	Cambridge.
Chas. O. Boutelle,	Washington, D.C.

Henry L. Eustis,	Cambridge.
James B. Francis,	Lowell.
John B. Henck,	Boston.
E. D. Leavitt, Jr.,	Cambridge.
William R. Lee,	Roxbury.
Frederic W. Lincoln,	Boston.
Hiram F. Mills,	Lawrence.
Alfred P. Rockwell,	Boston.
Charles S. Storrow,	Boston.
William R. Ware,	New York.
William Watson,	Boston.
Morrill Wyman,	Cambridge.

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SECTION I. — 8.

Geology, Mineralogy, and Physics of the Globe.

Thomas T. Bouvé,	Boston.
William T. Brigham,	Boston.
Algernon Coolidge,	Boston.
William O. Crosby,	Boston.
Jules Marcou,	Cambridge.
William H. Niles,	Cambridge.
Nathaniel S. Shaler,	Cambridge.
Charles U. Shepard,	Amherst.

SECTION II. — 8.

Botany.

William G. Farlow,	Cambridge.
George L. Goodale,	Cambridge.
Asa Gray,	Cambridge.
H. H. Hunnewell,	Wellesley.
Charles S. Sargent,	Brookline.
Charles J. Sprague,	Boston.
Edward Tuckerman,	Amherst.
Sereno Watson,	Cambridge.

SECTION III. — 22.

Zoölogy and Physiology.

Alex. E. R. Agassiz,	Cambridge.
Joel A. Allen,	Cambridge.
Robert Amory,	Brookline.
Nath. E. Atwood,	Provincetown.
James M. Barnard,	Boston.
Henry P. Bowditch,	Boston.
Edward Burgess,	Boston.
Samuel Cabot,	Boston.
John Dean,	Waltham.
Walter Faxon,	Cambridge.
Hermann A. Hagen,	Cambridge.
Charles E. Hamlin,	Cambridge.
Alpheus Hyatt,	Boston.
Samuel Kneeland,	Boston.
Theodore Lyman,	Brookline.
Charles S. Minot,	Boston.
Edward S. Morse,	Salem.
James J. Putnam,	Boston.
Samuel H. Scudder,	Cambridge.
D. Humphreys Storer,	Boston.
Henry Wheatland,	Salem.
James C. White,	Boston.

SECTION IV. — 21.

Medicine and Surgery.

Samuel L. Abbot,	Boston.
Henry J. Bigelow,	Boston.
Henry I. Bowditch,	Boston.
Benjamin E. Cotting,	Roxbury.
Frank W. Draper,	Boston.
Thomas Dwight,	Boston.
Robert T. Edes,	Boston.
Charles F. Folsom,	Boston.
Richard M. Hodges,	Boston.
Oliver W. Holmes,	Boston.
Robert W. Hooper,	Boston.
Alfred Hosmer,	Watertown.
Edward Jarvis,	Dorchester.
Francis Minot,	Boston.
John P. Reynolds,	Boston.
Wm. L. Richardson,	Boston.
George C. Shattuck,	Boston.
J. Baxter Upham,	Boston.
Charles E. Ware,	Boston.
John C. Warren,	Boston.
Henry W. Williams,	Boston.

Class III. — *Moral and Political Sciences.* — 62.

Section I. — 14.

Philosophy and Jurisprudence.

James B. Ames,	Cambridge.
Charles S. Bradley,	Providence.
Phillips Brooks,	Boston.
James F. Clarke,	Jamaica Pl.
Charles C. Everett,	Cambridge.
Horace Gray,	Boston.
John C. Gray,	Boston.
Laurens P. Hickock,	Northampton.
Oliver W. Holmes, Jr.,	Boston.
Mark Hopkins,	Williamstown.
C. C. Langdell,	Cambridge.
John Lowell,	Newton.
Henry W. Paine,	Cambridge.
James B. Thayer,	Cambridge.

Section II. — 17.

Philology and Archæology.

William S. Appleton,	Boston.
William P. Atkinson,	Boston.
Lucien Carr,	Boston.
J. T. Clarke,	Boston.
Henry G. Denny,	Boston.
Epes S. Dixwell,	Cambridge.
William Everett,	Quincy.
William W. Goodwin,	Cambridge.
Ephraim W. Gurney,	Cambridge.
Henry W. Haynes,	Boston.
Charles R. Lanman,	Cambridge.
Bennett H. Nash,	Boston.
Frederick W. Putnam,	Cambridge.
John L. Sibley,	Cambridge.
John W. White,	Cambridge.
Justin Winsor,	Cambridge.
Edward J. Young,	Cambridge.

Section III. — 20.

Political Economy and History.

Chas. F. Adams, Jr.,	Quincy.
Henry Adams,	Boston.
Edward Atkinson,	Boston.
John Cummings,	Woburn.
Charles Deane,	Cambridge.
George B. Dixwell,	Boston.
Charles F. Dunbar,	Cambridge.
Samuel Eliot,	Boston.
George E. Ellis,	Boston.
Edwin L. Godkin,	New York.
William Gray,	Boston.
Edward Everett Hale,	Boston.
Henry P. Kidder,	Boston.
Henry C. Lodge,	Boston.
Francis Parkman,	Boston.
Andrew P. Peabody,	Cambridge.
Joseph S. Ropes,	Boston.
Henry W. Torrey,	Cambridge.
Francis A. Walker,	Boston.
Robert C. Winthrop,	Boston.

Section IV. — 11.

Literature and the Fine Arts.

Charles F. Adams,	Boston.
George S. Boutwell,	Groton.
J. Elliot Cabot,	Brookline.
Francis J. Child,	Cambridge.
Charles G. Loring,	Boston.
James Russell Lowell,	Cambridge.
Charles Eliot Norton,	Cambridge.
Thomas W. Parsons,	Wayland.
Charles C. Perkins,	Boston.
H. H. Richardson,	Brookline.
John G. Whittier,	Amesbury.

ASSOCIATE FELLOWS.—85.

(Number limited to one hundred.)

Class I.—*Mathematical and Physical Sciences.*—33.

Section I.—7.

Mathematics.

E. B. Elliott,	Washington, D.C.
William Ferrel,	Washington, D.C.
Thomas Hill,	Portland, Me.
Simon Newcomb,	Washington, D.C.
H. A. Newton,	New Haven, Conn.
James E. Oliver,	Ithaca, N.Y.
T. H. Safford,	Williamstown, Mass.

Section II.—12.

Practical Astronomy and Geodesy.

W.H.C. Bartlett,	Yonkers, N.Y.
J. H. C. Coffin,	Washington, D.C.
Wm. H. Emory,	Washington, D.C.
Asaph Hall,	Washington, D.C.
J. E. Hilgard,	Washington, D.C.
George W. Hill,	Nyack, N.Y.
Sam. P. Langley,	Allegheny, Pa.
Elias Loomis,	New Haven, Conn.
Maria Mitchell,	Poughkeepsie, N.Y.
C. H. F. Peters,	Clinton, N.Y.
George M. Searle,	New York.
Chas. A. Young,	Princeton, N.J.

Section III.—10.

Physics and Chemistry.

F. A. P. Barnard,	New York.
J. Willard Gibbs,	New Haven, Conn.
S. W. Johnson,	New Haven, Conn.
John Le Conte,	Berkeley, Cal.
A. M. Mayer,	Hoboken, N.J.
Ogden N. Rood,	New York.
H. A. Rowland,	Baltimore.
L.M. Rutherfurd,	New York.
Benj. Silliman,	New Haven, Conn.
J. W. Mallet,	Charlottesville, Va.

Section IV.—4.

Technology and Engineering.

Henry L. Abbot,	New York.
William Sellers,	Philadelphia.
George Talcott,	Albany, N.Y.
W.P. Trowbridge,	New Haven, Conn.

Class II.—*Natural and Physiological Sciences.*—25.

Section I.—12.

Geology, Mineralogy, and Physics of the Globe.

George J. Brush,	New Haven, Conn.
James D. Dana,	New Haven, Conn.
J. W. Dawson,	Montreal, Canada.
J. C. Fremont,	New York.
F. A. Genth,	Philadelphia.
James Hall,	Albany, N.Y.
F. S. Holmes,	Charleston, S.C.
Clarence King,	Washington, D.C.
Joseph Le Conte,	Berkeley, Cal.
J. Peter Lesley,	Philadelphia.
R. Pumpelly,	Newport, R.I.
Geo. C. Swallow,	Columbia, Mo.

SECTION II. — 2.

Botany.

A. W. Chapman,	Apalachicola, Fla.
Leo Lesquereux,	Columbus, Ohio.

SECTION III. — 6.

Zoölogy and Physiology

S. F. Baird,	Washington, D.C.
J. C. Dalton,	New York.
Joseph Leidy,	Philadelphia.
O. C. Marsh,	New Haven, Conn.
S. Weir Mitchell,	Philadelphia.
A. S. Packard, Jr.,	Providence.

SECTION IV. — 5.

Medicine and Surgery.

Fordyce Barker,	New York.
John S. Billings,	Washington, D.C.
Jacob M. Da Costa,	Philadelphia.
W. A. Hammond,	New York.
Alfred Stillé,	Philadelphia.

CLASS III. — *Moral and Political Sciences.* — 27.

SECTION I. — 8.

Philosophy and Jurisprudence

D. R Goodwin,	Philadelphia.
A. G. Haygood,	Oxford, Ga.
R. G. Hazard,	Peacedale, R.I.
Nathaniel Holmes,	St. Louis, Mo.
James McCosh,	Princeton, N.J.
Charles S. Peirce,	New York.
Noah Porter,	New Haven, Conn
Jeremiah Smith,	Dover, N.H.

SECTION II. — 8.

Philology and Archæology.

A. N. Arnold,	Pawtuxet, R.I.
D. C. Gilman,	Baltimore.
A. C. Kendrick,	Rochester, N.Y.
A. S. Packard,	Brunswick, Me.
E. E. Salisbury,	New Haven, Conn.
A. D. White,	Ithaca, N.Y.
W. D. Whitney,	New Haven, Conn.
T. D. Woolsey,	New Haven, Conn.

SECTION III. — 6.

Political Economy and History.

George Bancroft,	Washington, D.C.
S. G. Brown,	Hanover, N.H.
Henry C. Lea,	Philadelphia.
J. H. Trumbull,	Hartford, Conn.
M. F. Force,	Cincinnati.
W. G. Sumner,	New Haven, Conn.

SECTION IV. — 5.

Literature and the Fine Arts.

James B. Angell,	Ann Arbor, Mich.
L. P. di Cesnola,	New York.
F. E. Church,	New York.
R. S. Greenough,	Florence.
William W. Story,	Rome.

FOREIGN HONORARY MEMBERS.—66.

(Appointed as vacancies occur.)

Class I.—*Mathematical and Physical Sciences.*—21.

Section I.—6.

Mathematics.

John C. Adams,	Cambridge.
Sir George B. Airy,	Greenwich.
Brioschi,	Milan.
Arthur Cayley,	Cambridge.
Charles Hermite,	Paris.
J. J. Sylvester,	Oxford.

Section II.—4.

Practical Astronomy and Geodesy.

Arthur Auwers,	Berlin.
Döllen,	Pulkowa.
H. A. E. A. Faye,	Paris.
Otto Struve,	Pulkowa.

Section III.—8.

Physics and Chemistry.

Berthelot,	Paris.
R. Bunsen,	Heidelberg.
M. E. Chevreul,	Paris.
H. Helmholtz,	Berlin.
A. W. Hofmann,	Berlin.
G. Kirchhoff,	Berlin.
Balfour Stewart,	Manchester.
G. G. Stokes,	Cambridge.
*C. A. Wurtz,	Paris.

Section IV.—3.

Technology and Engineering.

R. Clausius,	Bonn.
F. M. de Lesseps,	Paris.
Sir Wm. Thomson,	Glasgow.

Class II.—*Natural and Physiological Sciences.*—24.

Section I.—5.

Geology, Mineralogy, and Physics of the Globe.

Des Cloizeaux,	Paris.
James Prescott Joule,	Manchester.
C. F. Rammelsberg,	Berlin.
A. C. Ramsay,	London.
Bernhard Studer,	Berne.

Section II.—6.

Botany.

J. G. Agardh,	Lund.
George Bentham,	London.
Alphonse de Candolle,	Geneva.
Sir Joseph D. Hooker,	London.
Carl Nägeli,	Munich.
Julius Sachs,	Würzburg.

* Elected May 29th, 1883. Died May 12th, 1884.

SECTION III. — 9.

Zoölogy and Physiology.

Milne Edwards,	Paris.
Thomas H. Huxley,	London.
Albrecht Kölliker,	Würzburg.
Rudolph Leuckart,	Leipsic.
C. F. W. Ludwig,	Leipsic.
Richard Owen,	London.
Louis Pasteur,	Paris.
C. Th. von Siebold,	Munich.
J. J. S. Steenstrup,	Copenhagen.

SECTION IV. — 4.

Medicine and Surgery.

C. E. Brown-Séquard,	Paris.
F. C. Donders,	Utrecht.
Sir James Paget,	London.
Virchow,	Berlin.

CLASS III. — *Moral and Political Sciences.* — 21.

SECTION I. — 3.

Philosophy and Jurisprudence.

Sir Henry Sumner Maine,	London.
James Martineau,	London.
Sir James F. Stephen,	London.

SECTION II. — 7.

Philology and Archæology.

Georg Curtius,	Leipsic.
Pascual de Gayangos,	Madrid.
Benjamin Jowett,	Oxford.
Lepsius,	Berlin.
Max Müller,	Oxford.
H. A. J. Munro,	Cambridge.
Sir H. C. Rawlinson,	London.

SECTION III. — 7.

Political Economy and History.

Ernst Curtius,	Berlin.
W. Ewart Gladstone,	London.
Charles Merivale,	Ely.
Mommsen,	Berlin.
Mark Pattison,	Oxford.
Von Ranke,	Berlin.
William Stubbs,	Oxford.

SECTION IV. — 4.

Literature and the Fine Arts.

Matthew Arnold,	London.
Gérôme,	Paris.
John Ruskin,	Coniston.
Lord Tennyson,	Isle of Wight.

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